ESMRO
STUDY PROGRAM

FINAL REPORT

Volume II
Technical

Prepared for

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER

BBRC
BALL BROTHERS RESEARCH CORPORATION
SUBSIDIARY OF BALL BROTHERS COMPANY INCORPORATED
BOULDER, COLORADO

EXPERIMENTS FOR SATELLITE AND MATERIAL RECOVERY FROM ORBIT

STUDY PROGRAM

F67-05

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GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

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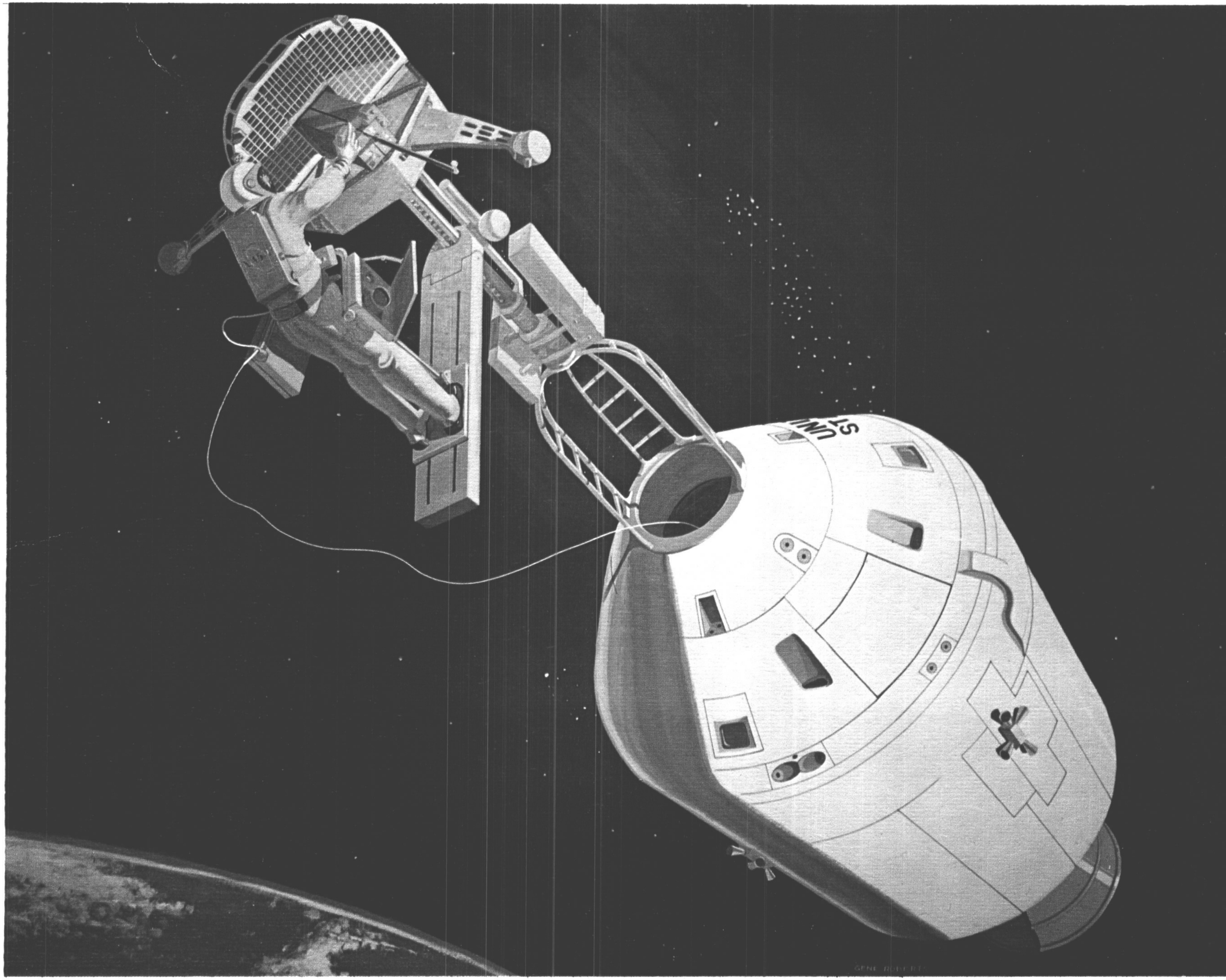

SATELLITE CAPTURE WORK PLATFORM / APOLLO

BALL BROTHERS RESEARCH CORPORATION

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TABLES

GLOSSARY

AAP	Apollo Applications Program
AC	alternating current
AMU	astronaut maneuvering unit
BBRC	Ball Brothers Research Corporation
CG	center of gravity
CM	Command Module
C. M.	center of mass
COR	Contracting Officer Representative
CSM	Command Service Module
CWP	Capture Work Platform
DC	direct current
DOF	degree of freedom
EE	Emerson Electric Company of St. Louis
emf	electro magnetic force
ESMRO	Experiment for Satellite and Material Recovery from Orbit
EVA	extra vehicular activity
FFD	functional flow diagram
fps	feet per second
GP	general purpose
GSFC	Goddard Space Flight Center
G&N	guidance and navigation system
HCO	Harvard College Observatory
HHMU	hand held maneuvering unit

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IGS	inertial guidance system
IVA	intra vehicular activity
LEM	Lunar Excursion Module
LOS	line of sight
LWIR	long wave infrared
MCS	Mission Control Center
m (km)	meter (kilometer)
MOI	moment of inertia
mps	meters per second
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MSC	Manned Spacecraft Center
MSO	mission support operation
NASA	National Aeronautics and Space Administration
nm	nautical miles
NRL	Naval Research Laboratory
OCS	on-board checkout system
OSO	Orbiting Solar Observatory
P	primary objective
PLSS	portable life support system
RCS	reaction control system
RF	radio frequency
rpm	revolution per minute

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S	secondary objective
S/C	spacecraft [i.e., Apollo (CSM)]
SLA	spacecraft LEM adapter
SM	Service Module
SPS	service propulsion system
TBD	to be determined
T/S	target satellite (i.e., OSO)
UV	ultraviolet

ΔV	delta velocity
$\Delta\Omega$	difference in longitudes of the ascending nodes (i.e., $\Omega_{OSO} - \Omega_{CSM} = \Delta\Omega$)
V_2	true anamoly of OSO
$\Delta\psi$	phasing angle
$\Delta\Phi$	transfer angle
$\vec{P}_1$	position of CSM at beginning of transfer trajectory
$\vec{P}_2$	position of CSM/OSO at time of rendezvous
i	orbit inclination angle
Δi	variation in inclination angle
e	eccentricity
Δe	variation in orbit eccentricity
a	plane change angle
$\Delta\omega$	difference in argument of perigee
$\vec{h}$	angular momentum vector of the orbit
α	aiming angle for station keeping thrusting

DEFINITIONS

Capture	The operation which includes physically contacting and containing the OSO. Capture of the OSO requires that it be contained, under control of the CSM, and that it be brought into kinetic equilibrium with the CSM.
Capture mechanism	The device or system for accomplishing the capture of the OSO satellite.
Coplanar orbit transfer	The coplanar transfer starts with the CSM in a 370 km (200 nm) parking orbit with an inclination the same as OSO (32.85 degrees), the CSM then makes a transfer to the OSO orbit.
Coupled (capture) system	A device which is physically coupled to the CSM during the capture and stabilization of the OSO.
Functional analysis	A rigorous systems review which details the functional flow and operations, and establishes requirements of a program and/or system.
Independent (capture) system (free)	A device that would be maneuvered from the CSM, and which would independently effect capture of the OSO.
Out of plane orbit transfer	The out of plane transfer combines a plane change and orbit transfer in a two impulse maneuver of the CSM.
Plane change/coplanar orbit transfer	This orbital transfer approach considers the CSM to be in a nominal 370 km (200 nm) altitude parking orbit with an inclination of 28.5 degrees while the OSO orbit has a 32.85 degree inclination. The CSM makes a plane change from its parking orbit so that its plane is coplanar with the OSO, and then makes a transfer to the OSO orbit.
Rendezvous	Rendezvous is the orbital operation which includes the CSM orbit transfer from its parking orbit to the OSO orbit; the performance of terminal guidance to effect closure of the CSM with the OSO satellite; and the performance of a station keeping mode between the CSM and OSO in preparation for capture operations with the OSO.
Rigid (capture) system	A device attached to the CSM during the capture and stabilization of the OSO which would not permit motion between the OSO/capture mechanism/CSM except for small structural deflections.

Satellite	Satellite or target satellite as used in this report defines the space object which is to be captured, and on which useful work is to be conducted, (i.e., the Orbiting Solar Observatory - OSO).
Semirigid (capture) system	A device attached to the CSM during the capture and stabilization of the OSO which would permit small relative motion between the OSO/capture mechanism/CSM.
Spacecraft	The word spacecraft as used in this report defines the manned space vehicle which is used to perform rendezvous and capture operations with the target satellite, (i.e., the Apollo Command Service Module - CSM).
Station keeping	The maneuvering operation of the CSM in close proximity with the OSO.
Tethered (capture) system	A device which is flexibly attached or coupled to the CSM during the capture and stabilization of the OSO.
Useful work	Useful work is the operation or performance of experimental tasks on the OSO in orbit, including inspection, material retrieved, refurbishment, and checkout.

SECTION 1

INTRODUCTION

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Section 1
INTRODUCTION

This volume presents the results of the seven month technical requirements study to develop three missions for the retrieval of materials from an Orbiting Solar Observatory (OSO), and to refurbish an OSO in orbit. The OSO satellite is illustrated in Fig. 1-1. The study program, entitled Experiments for Satellite and Material Recovery from Orbit (ESMRO), has been conducted by the Ball Brothers Research Corporation, Boulder, Colorado, and its subcontractor, the Emerson Electric Company of St. Louis, St. Louis, Missouri, for the Marshall Space Flight Center under contract No. NAS8-18119. The primary objectives of this study are: (1) the development of three retrieval/refurbishment missions, evolutionary in nature; (2) the capture of noncooperative satellites; and (3) the performance of useful work during extra vehicular activity (EVA). The fulfillment of these objectives provides a basis for an EVA program leading toward a long range routine operational capability for recovery of objects from earth orbit. Various members of the scientific community have been consulted for input to this study as well as the NASA Goddard Space Flight Center OSO Project Office. The MSC Flight Crew Operations Directorate has also provided valuable input to various program concepts.

This volume of the report is organized to present the technical study results in each major area. The study approach is given in Section 2, which includes the guidelines under which the study was conducted. Section 3 covers the study results in the area of rendezvous, and the capture/release study results are given in Section 4. The study results in the area of useful work are discussed in Section 5. Each of these sections presents the trade-off analyses considered, reviews the major alternatives, and includes a recommended approach summary. In accordance with the contract, orbital parameters expressed throughout are provided in the International System of Units with the English gravitational equivalent given in parentheses immediately thereafter.

The three ESMRO mission program plans are presented in Sections 6, 7, and 8, respectively. These plans include: (1) the mission objective, (2) mission characteristics, (3) mission operations, (4) integrated timeline analysis, and (5) expected significant results. The detailed descriptions of each functional task peculiar to the mission are covered under mission operations. The overall technical requirements for the three missions as they affect the CSM, the OSO, the crew and mission operations, and the ESMRO hardware configuration, are presented in Section 9.

Reference data on the OSO, the rendezvous calculations, the capture dynamics calculations, and the functional flow diagrams are presented in the appendices.

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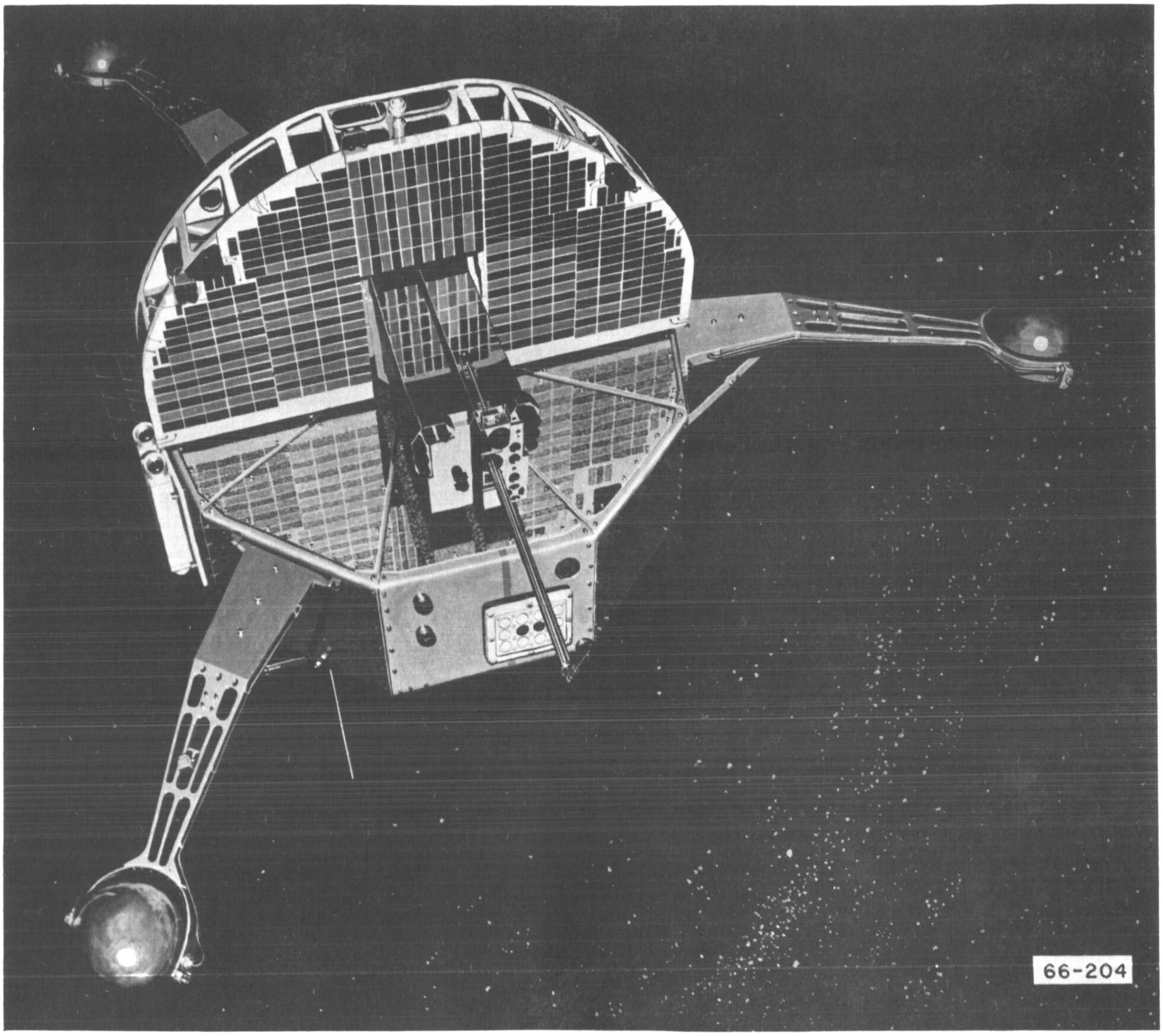

Fig. 1-1 OSO General Configuration

SECTION 2

STUDY APPROACH

Section 2
STUDY APPROACH

The approach to this study was to first develop a program plan for the conduct of the study and then carry out the plan which was approved by NASA/MSFC. This program plan called for three phases to be performed:

- Experiment mission conception
- Experiment mission definition
- Final report preparation

The results of the experiment mission conception phase were approved by NASA/MSFC approximately two months after initiation of the program as shown in Fig. 2-1. Also shown in this figure are the various briefings that were performed during the course of the study. The program plan and the scope of each of the study phases is discussed in the following sections.

2.1 PROGRAM PLAN

The study program plan was prepared during the first three weeks of the program; this established the criteria and constraints governing the study and the technical phases to be performed. This program plan was approved by the NASA/MSFC – COR on 3 August 1966.

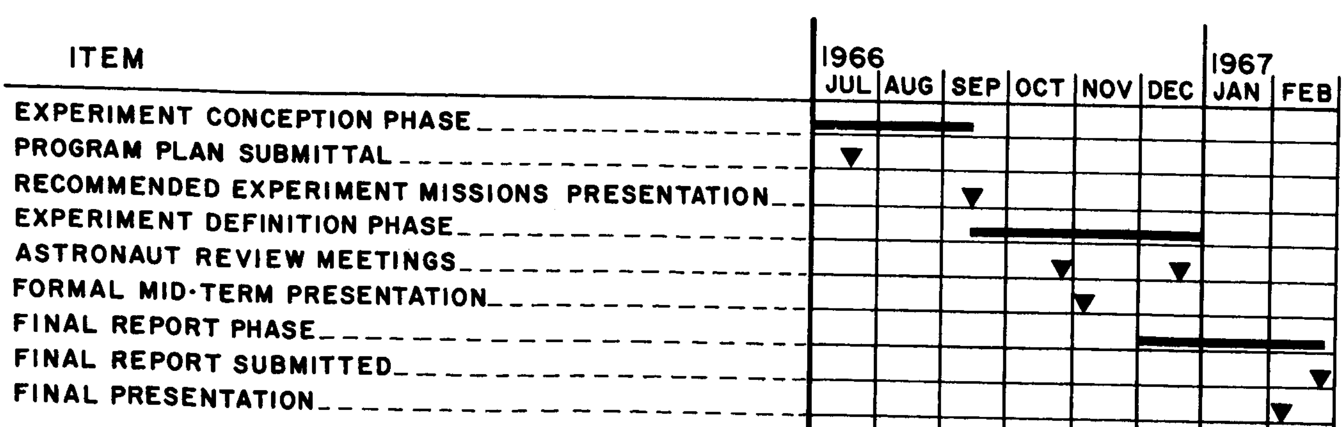

Fig. 2-1 ESMRO Study Program Schedule

2.1.1 Mission Criteria

In order to establish well defined plans for the three experiment missions, the following criteria have been established.

(1) Mission 1 will be oriented toward the development of EVA techniques and supporting mechanisms to be used principally in the experiments calling for retrieval of materials, while Mission 2 and 3 will be related to refurbishment techniques and associated experiments. These criteria makes possible a progressive evolution in EVA technology and experiment complexity.

(2) All missions must consider the availability of OSO's at the time of the mission and the accessibility of parts and components to be handled; any possible OSO modifications to facilitate the performance of experiments must also be assessed. Modifications can be considered only to the extent allowable in the specific OSO project schedule.

(3) Planned experiment missions must evaluate the availability of EVA support equipment and technology for the time frame of each mission.

(4) Experiment missions must be planned so that there is a reasonable method of evaluating the accomplishments, both of the EVA and the effects of operations on the OSO.

(5) Certain experiments are prerequisite to the completion of successful missions. These must be evaluated and identified so that it becomes mandatory to include them in their respective planned mission.

(6) Mission experiments may be successfully performed if they are supported by adequate training and simulation prior to attempting the flight mission. Selection of experiments must therefore be considered with respect to the probable requirements and feasibility of training for the planned EVA.

(7) To refurbish a satellite for continued or prolonged utility, repairs or replacement must be directed to the portion that is malfunctioning. Experiments must be selected so that the most probable malfunctions can be remedied; or else, comparable operations that are versatile enough to allow decision points are to be made with respect to the indicated failure or malfunction. Necessary or required functional operations must be considered in planning these somewhat versatile experiment missions.

(8) Mission experiments planned on a practical basis must consider implementation within the state-of-the-art for the time frame of each mission.

(9) Development of EVA technology is considered the prime mission for these experiments. Each experiment must also provide a desirable scientific and space engineering; for example, retrieval of material to evaluate the long term effects of space environment, advancement of refurbishment techniques, or improved OSO or other spacecraft design innovations.

2.1.2 Constraints

All experiments must be planned within certain constraints imposed by the nature of the program. These constraints are imposed by the scope of this study program, the CSM astronaut capabilities, and the OSO. These constraints are as follows:

2.1.2.1 Study Program Constraints

(1) Recommended experiments shall be self sufficient to the maximum extent practical.

(2) Flight experiment mission time frame shall be 1969 to 1972.

(3) Maximum utilization shall be made of existing hardware and technology.

(4) Conduct of the experiments defined under this study shall be considered not as the singular, but rather as the primary objective of the mission on which they are flown.

(5) Design concepts developed under this study shall, to the maximum extent feasible, be adaptable to a wide range of earth orbital satellites and refurbishment missions.

(6) No detail design shall be accomplished under this study.

(7) The manned spacecraft from which experiments defined under this study are to be conducted shall be the Apollo CSM.

(8) The target satellite shall be the OSO.

(9) Crew safety shall be maximized.

(10) Conceptual experiments shall be defined to the extent required by NASA form 1138.

(11) Computer programs for orbital transfer and rendezvous analysis shall be provided by NASA when available.

2.1.2.2 Apollo Constraints

The mission constraints are the following:

(1) The Apollo orbit parameters considered shall be a 370 km (200 nm) Earth orbit at 28.5 degree (32.85 degree alternate) nominal inclination with the Earth's equator.

(2) The Apollo spacecraft and mission considered shall be the CSM Block II and a 14 day mission, respectively.

The spacecraft constraints are the following:

(1) Modifications to the CSM shall be minimized.

(2) Interface complexity with the CSM shall be minimized.

(3) Mechanisms used to capture and hold the OSO shall be jettisoned; they shall not be restowed in the CSM after completion of the experiment mission.

(4) The capture device and flight support equipment shall be compatible with Sector I of the Service Module (SM), if this area becomes available for experiments.

a. The structural load carrying limit of the SM Sector I is 5,000 pounds.

b. The Sector I dimensions are 151 inches long, 50.5 inches high, 17 inches wide at the inboard edge, and 62.5 inches wide at the outboard edge.

c. The Sector I volume is 179 cubic feet.

(5) The center of gravity of the capture mechanism and ESMRO flight support equipment, if stowed in the Sector I bay of the Service Module, shall not exceed the gimbal angle envelope of the SPS engine.

(6) The CSM can supply both DC power at a nominal 27.5 volts and AC power at 115 volts, 3 phase, 400 Hertz, 400 kilowatt hour of equivalent DC power on a nonessential basis.

(7) Storage space required for the return of retrieved material, experiments and equipment from orbit shall be compatible with existing Command Module storage areas.

(8) It is assummed that CSM propellant consumption expended during satellite tracking, rendezvous, capture operations, and in-orbit operations will not exceed that required for an equivalent 762 mps (2500 fps) of delta velocity.

2.1.2.3 Astronaut Constraints

(1) All features of operating the capture mechanism must make provision for the practical problem of the astronauts dual tasks of controlling the CSM and operating the capture mechanism.

(2) During EVA operations, the crew in the CM will be in spacesuits. All capture mechanism operations, both from within the CSM and during EVA must be conductable while the astronaut is in a spacesuit. All switches should be operable with a gloved hand and critical switches should be covered; this will require two steps to actuate. Indicators should be avoided unless required to operate the capture mechanism or unless the crew can implement corrective action.

(3) The estimated astronaut time available for ESMRO experiments during a given mission will be from 5 to 8 hours per day per man. There will be three astronauts in the CM.

(4) The crew member(s) performing EVA will wear a pressure over garment suit and EVA gloves. All work effort, manipulations, operations, must be conductable with bulky gloves and the limitations imposed by the spacesuit. All EVA planning must take into account limitations imposed by the zero-G-environment, total darkness, direct sunshine, and the astronaut's tether. Waist tethers, and hand and/or foot hold devices will be required to perform operations on the OSO.

(5) Items to be recovered from the OSO for return to earth must be securely constrained (i.e., boxed, sacked, tethered) so that it is not inadvertantly lost by the astronaut, contaminated in the handling operations, and/or converted to unnecessary space debris.

(6) Items to be recovered must be of a size that can be handled and maneuvered by the astronaut under the conditions and constraints specified above.

2.1.2.4 OSO Constraints

(1) OSO capture operations must be nondestructive.

(2) OSO related ESMRO experiments must not impair any objectives of the OSO missions.

(3) Prelaunch modifications required on existing OSO's must not effect their reliability or mission plans.

(4) The OSO must be assummed noncooperative.

2.1.3 Technical Study Phases

The technical study phases defined in the program plan are:

- Experiment mission conception phase
- Experiment mission definition phase

The experiment mission conception phase was intended to formulate potential experiment tasks into three preliminary mission program plans. The experiment mission definition phase was intended to cover detailed trade-off studies, calculations and OSO task definition, resulting in completion of the NASA form 1138 for each of the three missions. The performance of these study phases is discussed in Sections 2.2 and 2.3 respectively.

2.2 EXPERIMENT MISSION CONCEPTION PHASE

The experiment mission conception phase of the study included effort to (1) categorize experiments, (2) conceive experiments, and (3) evaluate experiments. This effort has defined the scope of the three missions and is discussed in the following sections.

2.2.1 Experiment Categorization

All possible experiments that could be performed during an ESMRO mission were grouped into major categories. The categories selected to represent this grouping are the following:

- Inspection
- Material retrieval
- Refurbishment
- Improvement

2.2.2 Experiment Conception

A large number of experiment tasks were conceived in each of the above categories. The level of definition for each of these experiment tasks, was such that typical tasks on target OSO's were defineable. The large number of tasks was itemized under the applicable category for further review.

2.2.3 Experiment Evaluation

Each of the experiment tasks that was nominated was extensively reviewed and evaluated. Evaluation criteria used are the following:

- Enhancement of EVA technology (x2)
- Advancement of space environment knowledge
- Scientific and engineering value
- Enhancement of OSO capabilities
- Minimum hardware development
- Ease of accomplishment (x2)
- General desirability

The weight factor for the "Enhancement of EVA technology" and for "Ease of accomplishment" was twice that of the other evaluation criteria. This was to account for the intrinsic value of each experiment to the primary objective of advancing the state-of-the-art of EVA technology as well as to assist in separating tasks by complexity to develop missions of evolutionary complexity. The evaluation also took into account the preliminary analysis of EVA complexity that was performed on each experiment task.

This evaluation was reviewed to determine those experiment tasks with the highest rating. No arbitrary limits were established to eliminate experiment tasks, but low ranking tasks received a low priority rating for inclusion in the trade-off studies and mission planning during the definition phase.

2.3 EXPERIMENT MISSION DEFINITION PHASE

The experiment mission definition phase included the functional analysis of all operational steps in the mission and the detailed development of the mission plans. These are discussed in the following sections.

2.3.1 Functional Analysis

Each phase of the ESMRO mission was analyzed functionally to determine the requirements of the operations. Functional analysis is a rigorous systems review that details the functional flow and operations of the program phases. The analysis procedure followed was to define the major steps required to conduct an ESMRO mission as shown in Fig. 2-2. Of the eight functional operations shown, only the "Perform ESMRO Mission" function was analyzed in more detail, since it has been established as the main objective of this study.

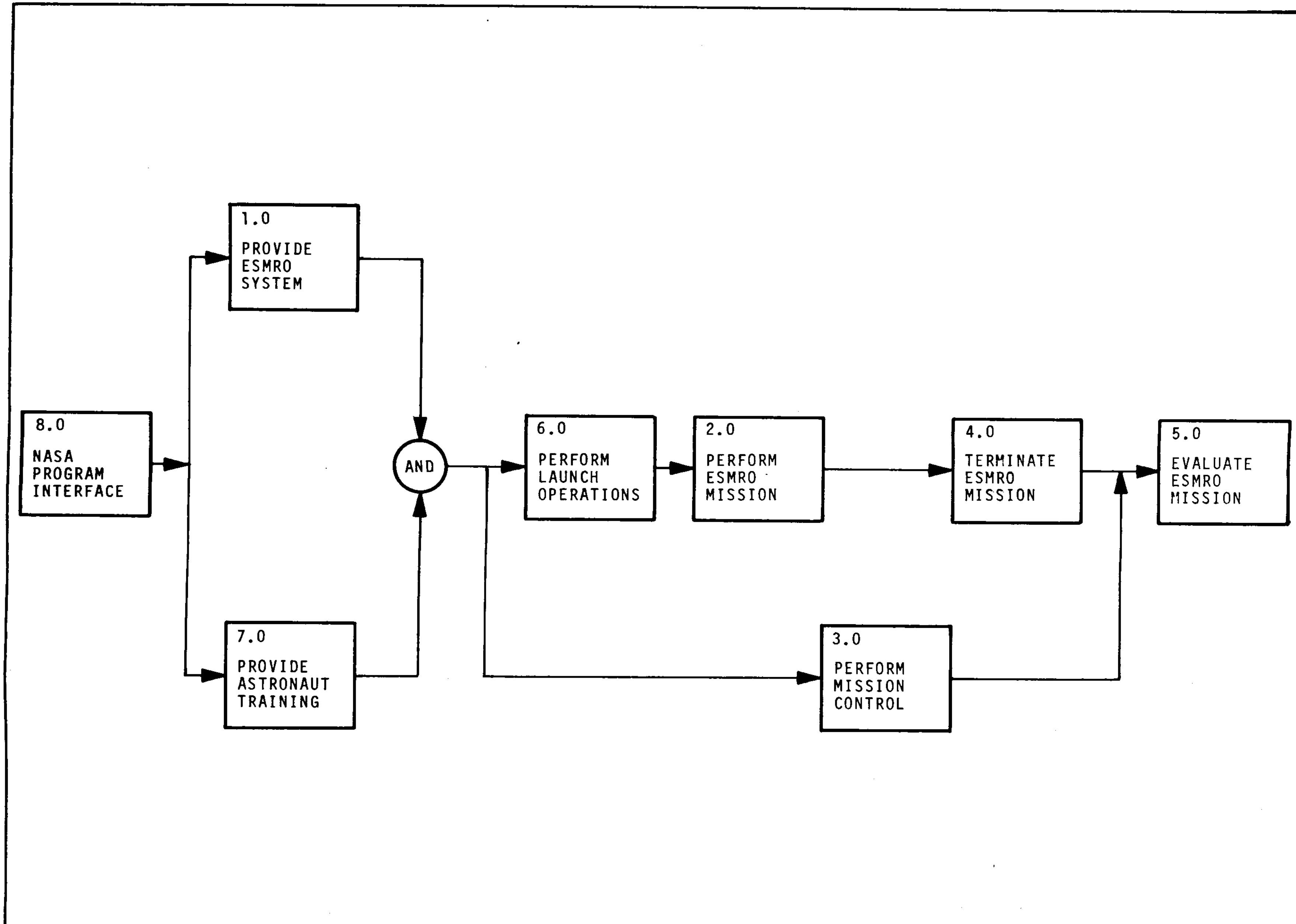

Fig. 2-2 ESMRO Functional Flow Diagram - Top Level

The next functionally analyzed level is shown in Fig. 2-3. The major phases of an ESMRO mission are defined in this functional flow diagram. Each of these phases has been analytically evaluated to define the operational requirements. The functional flow diagrams that describe these requirements are included in Appendix E. The requirements developed from this analysis have formed the basis of the trade-off and other technical studies of this program. The complete functional analysis for the ESMRO program has provided assurance that all major requirements have been identified for study.

2.3.2 Mission Plan Development

The major effort of this phase of the study was to develop a mission plan for each of three ESMRO missions. These plans are presented in Sections 6, 7, and 8. They indicate in detail the useful work effort and the EVA time line analysis.

The mission plans are based on the recommended approaches to rendezvous and capture and on the recommended experiments tasks. These tasks have been extensively evaluated to determine the procedural steps required to perform them. The timeline analysis of each task has been based on evaluation of laboratory time estimates by OSO technicians and on simulation using mockups, as well as on the advice and recommendations from members of the MSC Astronaut Office.

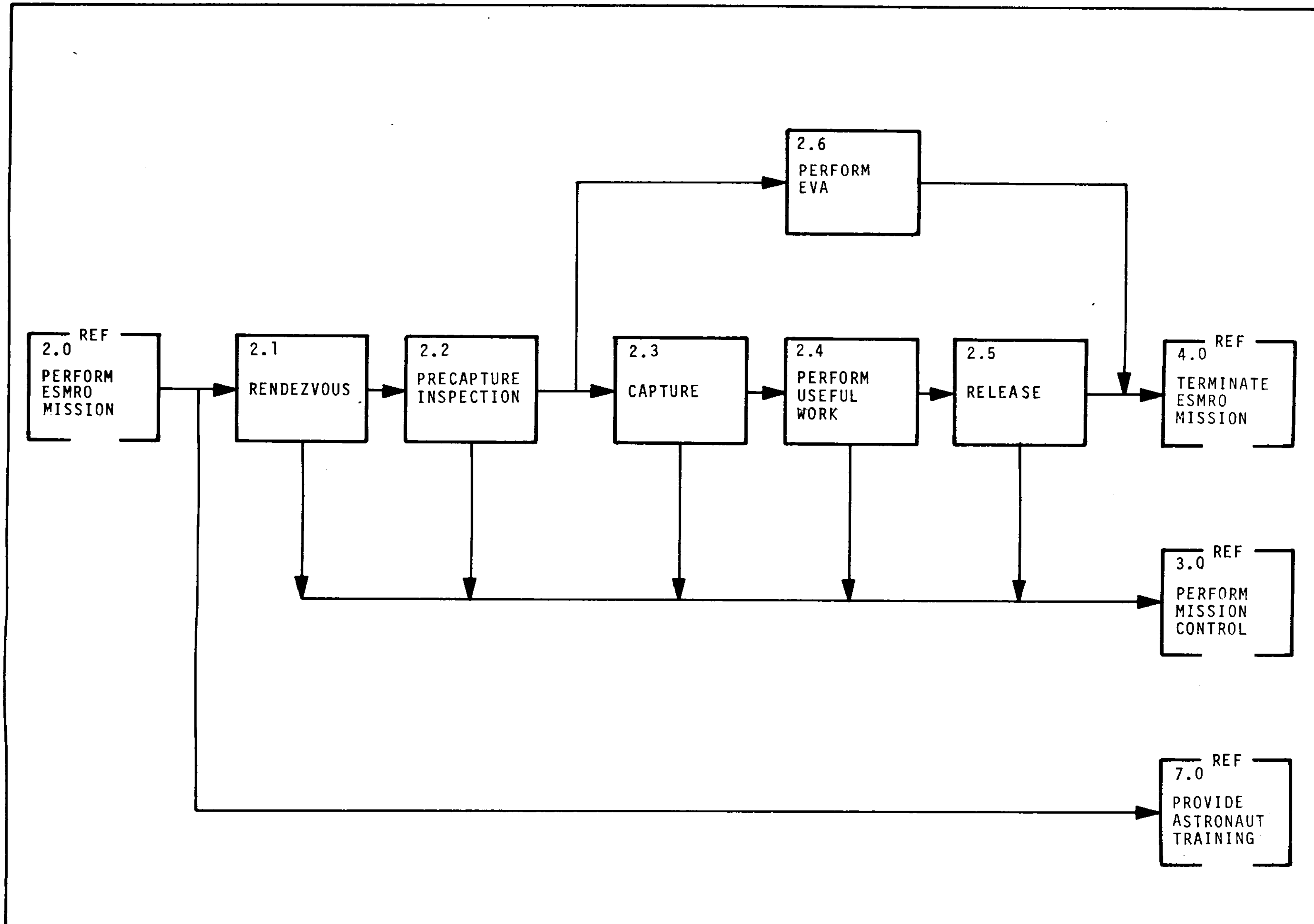

Fig. 2-3 Perform ESMRO Mission - FFD

SECTION 3

RENDEZVOUS

Section 3
RENDEZVOUS

The rendezvous phase of the ESMRO mission encompasses all maneuvers which bring the CSM from its initial parking orbit into position to effect capture of OSO. These maneuvers include transfer of the CSM from its parking orbit to the OSO orbit; terminal closure of the CSM to OSO; and CSM station keeping about OSO.

The criteria, constraints and functional requirements for this phase of the mission are described below. Techniques for accomplishing orbital transfer, terminal closure and station keeping are analyzed, and a recommended rendezvous procedure is presented.

3.1 GENERAL CONSIDERATIONS

The general considerations that have significantly affected the rendezvous studies include: (1) criteria, constraints, and initial conditions; (2) functional requirements; and (3) approaches considered.

3.1.1 Criteria, Constraints and Initial Conditions

The major criteria and constraints established by MSFC that have affected the rendezvous studies are:

(1) The Apollo CSM is to be used to transfer from its parking orbit to the target OSO.

(2) The target OSO will be noncooperative.

(3) The maximum delta velocity (ΔV) assumed available in this study for rendezvous maneuvers is 762 mps (2500 fps). (This ΔV budget is considered to be conservative.)

In addition to the above criteria and constraints, MSFC has provided the following parking orbit conditions for the Apollo CSM to be used for the rendezvous analysis:

Orbital Elements	Nominal Values	(Specified Variations)
Perigee	368 km (199 nm)	
Apogee	372 km (202 nm)	
Semimajor axis (a)	6748 km (3664 nm)	
Eccentricity (e)	0.00024	(±0.00021)
Normal Inclination (i)	28.5 deg	(±0.008 deg)
Alternate Inclination (i)	32.85 deg	

Typical OSO orbit elements used in the rendezvous studies are given on the following page:

Orbital Elements	Nominal Values	(Specified Variations)
Perigee	548 km (297 nm)	
Apogee	604 km (328 nm)	
Semimajor Axis (a)	6954 km (3776 nm)	
Eccentricity (e)	0.004	(±0.002)
Inclination (i)	32.85 deg	(±0.1 deg)
Period	96.2 min	
Maximum Orbital Day	70.6 min	
Minimum Orbital Day	59.8 min	

3.1.2 Functional Requirements

The functional requirements for the rendezvous phase are established by analysis of function 2.1 "Rendezvous" on Fig. 2-3. This function is detailed in Fig. 3-1, to indicate the main subfunctions and the flow logic of performing rendezvous.

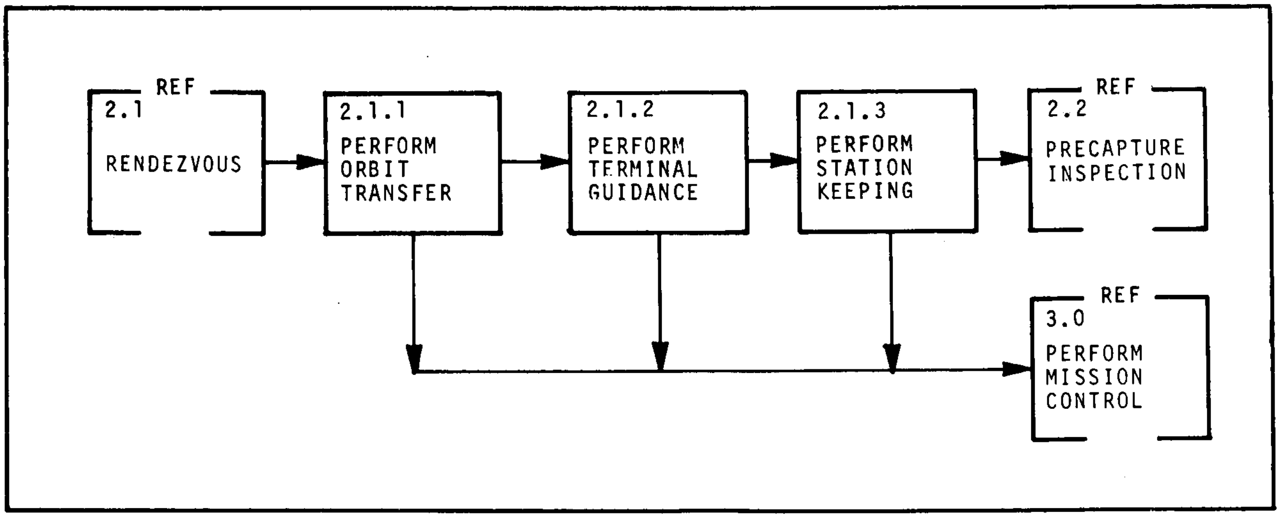

Fig. 3-1 Rendezvous - FFD

The rendezvous function consists of three main functional efforts: (1) Function 2.1.1, "Perform Orbit Transfer;" (2) Function 2.1.2, "Perform Terminal Guidance;" (3) Function 2.1.3 "Perform Station Keeping." Each of these efforts has been functionally analyzed in more detail which can be found in Appendix E (Functional Flow Diagrams).

Orbit Transfer. The orbit transfer entails: (1) the establishment of guidance parameters while the CSM is in a parking orbit; (2) the orientation and thrusting of spacecraft, and (3) a verification of terminal orbit ephemeris. For the purpose of the rendezvous studies conducted, only thrusting requirements required to perform the CSM orbit transfer were considered. In the rendezvous transfer analysis, it was assumed that the thrusting impulse is initiated and terminated instantaneously. It was also assumed that a plane change in the parking orbit, if necessary, is also applied in this manner. It has since been verified that the difference in ΔV between this approach and a thrust impulse integrated over a finite interval is less than 3 mps (9.8 fps) for a minimum energy Hohmann transfer.

Terminal Closure. Terminal closure includes the guidance and maneuvers to compensate for uncertainties and errors in the rendezvous transfer. During closure, an onboard sensor provides current data on the angular position of OSO. This data, together with apriori information and astronaut visual observations, identifies the thrusting required for the closure maneuver.

Station Keeping. Station keeping maneuvers by the CSM are required for inspection of the OSO satellite prior to capture and for preparation of capture operations. Station keeping maneuvers were established for both the day portion, including circumnavigation, and the night portion of the orbit.

3.2 ORBIT TRANSFER

The orbit transfer maneuvers were analyzed to determine the total velocity increment (ΔV) required to transfer the CSM from its parking orbit to the orbit of OSO.

This ΔV is a function of the semimajor axis and eccentricity of the ellipse of which the transfer trajectory is an arc. The time, and the phasing necessary before initiating transfer to OSO has also been determined. The mathematical model developed for this analysis is presented in Appendix B. The computer program considers the position vector of the CSM at the initiation of the orbit transfer trajectory and the position vector of the CSM/OSO at the completion of rendezvous.

Three techniques for performing the orbit transfer were considered: (1) an out-of-plane transfer, (2) a plane change/coplanar transfer, and (3) a coplanar transfer. The out-of-plane transfer combines the plane change and ascent to orbit in a single two-impulse maneuver. One thrust impulse initiates the orbit transfer, and the second injects the CSM into the OSO orbit. The plane change/coplanar transfer consists of an impulsive plane change maneuver at the altitude of the parking orbit followed by a two-impulse coplanar ascent to the OSO orbit. The coplanar transfer assumes that the CSM parking orbit is established in the plane of the OSO orbit and that a two-impulse coplanar ascent is made to the orbit of OSO. The third technique is obviously a special case of the plane change/coplanar transfer technique. The geometry of these three techniques is illustrated in Fig. 3-2.

The majority of the analyses were conducted using the nominal values of the inclination, semimajor axis and eccentricity of the orbits of the CSM and OSO. The CSM is initially in a 28.5 degree inclination, 6748 kilometer (3664 nautical mile) semimajor axis orbit of 0.00024 eccentricity. Its position in orbit was arbitrarily fixed at a mean anomaly of 0 degree with an argument of perigee of 10 degrees. The OSO satellite is assumed to be in 32.85 degree inclination with a 6954 kilometer (3776 nautical mile) semimajor axis orbit of 0.004 eccentricity. The argument of perigee of the OSO orbit has been established at 2 degrees.

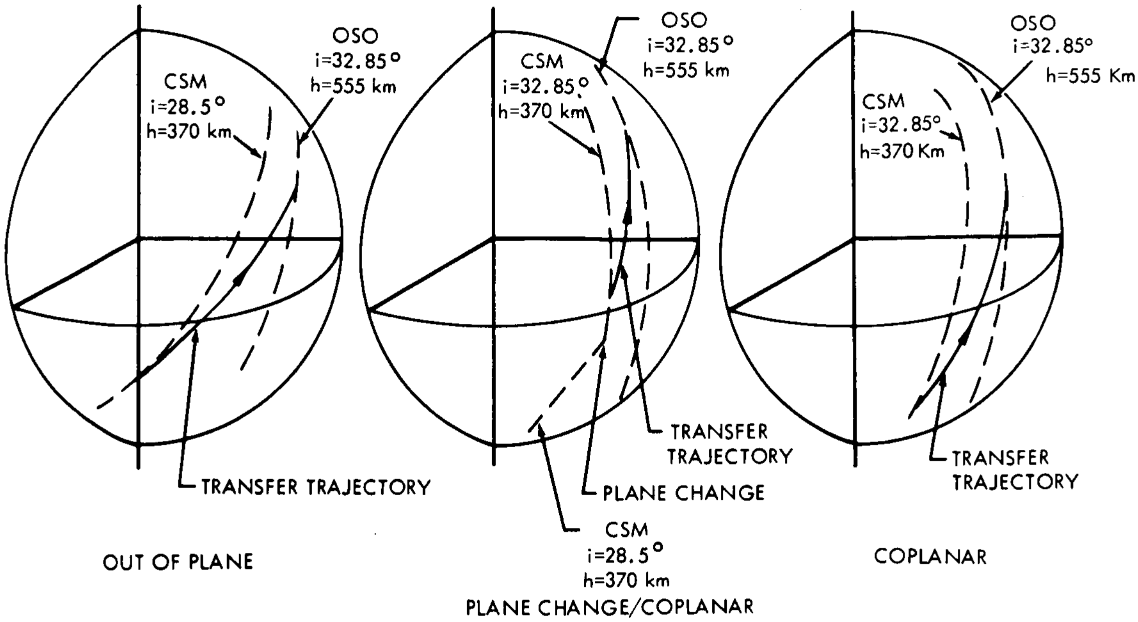

Fig. 3-2 Rendezvous Approaches

A series of variations were introduced to prove that the results using the nominal values were representative. First, the eccentricity and inclination of the CSM orbit were varied separately, while all the other elements were held at their nominal values. Secondly, the eccentricity and inclination of the OSO orbit were varied separately, while all other elements were held at their nominal values. Thirdly, the eccentricities and inclination of the orbits of OSO and the CSM were held at the nominal values while the arguments of perigee of OSO and the CSM, and the mean anamoly of the CSM were varied, separately and in combination. The analyses indicated that the expected variations about the nominal OSO and CSM orbits did not significantly effect the total ΔV required for rendezvous.

3.2.1 Out of Plane Transfer

The out of plane transfer combines a plane change and ascent to the OSO orbit in a single two-impulse maneuver. The geometry of this transfer with respect to a geocentric coordinate system is illustrated in Fig. 3-3. Vector P_1 locates the position of the CSM at the beginning of the transfer trajectory, and vector P_2 locates the position of the CSM and OSO at the time of rendezvous. The transfer trajectory required for rendezvous is in the plane of vectors P_1 and P_2 and connects their end points.

The digital computer program used in this study calculates the transfer angle between the two vectors, the time for transfer, and the phase angle locating the position of OSO at the instant the CSM begins its transfer trajectory.

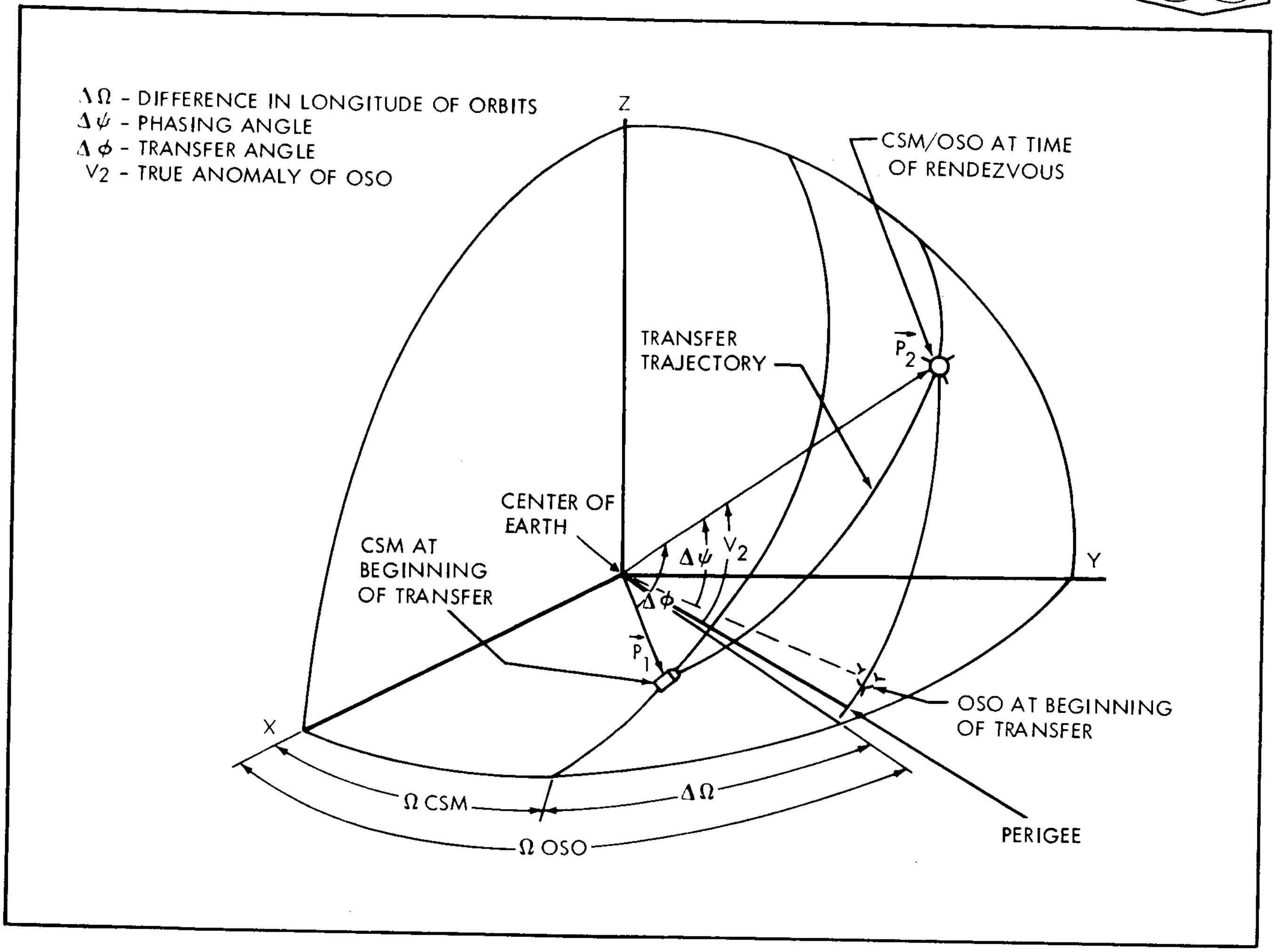

Fig. 3-3 Rendezvous Out of Plane

The initial analyses considered the OSO and the CSM in their nominal orbits with the difference in longitude of the descending node being the only geometric variant. Following the analyses of the nominal case, the effect of variations in the orbital elements about their nominal values was considered.

Analysis of Transfer–Nominal Orbits. The velocity increments were computed as a function of the differences in the longitude of the ascending nodes of the orbits of the OSO and the CSM. The orbits of the OSO and the CSM were established in their nominal orbits indicated below:

Orbital Elements	CSM	OSO
Inclination	28.5 deg	32.85 deg
Eccentricity	0.00024	0.004
Semimajor axis	6748 km	6954 km
Argument of perigee	10 deg	2 deg
Mean anomaly at start of transfer	0 deg	N.A.

The velocity increment required for the CSM to transfer from its initial position and rendezvous with the OSO is presented in Fig. 3-4 as a function of the true anomaly of OSO at the time of rendezvous. The velocity increment required can also be related to the CSM transfer angle and the OSO phase angle since both these angles are related to the OSO true anomaly (Fig. 3-5).

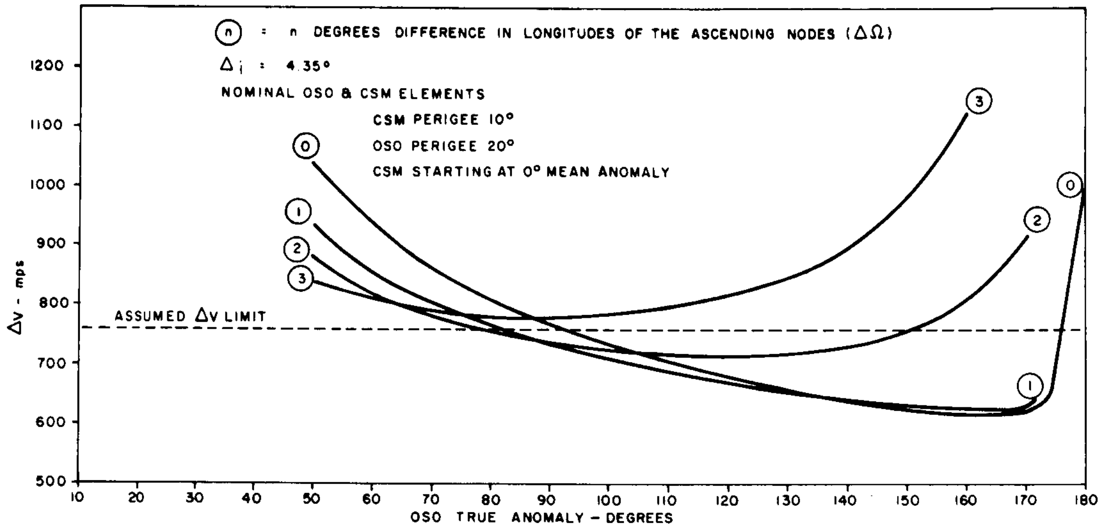

Fig. 3-4 Out of Plane ΔV Requirements

The figure illustrates that for a conservative ΔV allowance of 762 mps, rendezvous is feasable at differences in longitude of the ascending nodes of less than 3 degrees. Greater differences in longitude will require additional ΔV; this is discussed in more detail in the next section describing plane change/coplanar transfer. Within the conservative ΔV allowance (762 mps), the OSO true anomaly at rendezvous may vary between about 80 degrees (at $\Delta\Omega=2°$) and 170 degrees (at $\Delta\Omega=0°$). These angles correspond to a CSM transfer angle range of 75 to 170 degrees and an OSO phase angle range of 70 to 165 degrees.

With each value of $\Delta\Omega$, the slope of the curve is relatively shallow over a wide range of OSO true anomaly. For example, with $\Delta\Omega$ of one degree, the transfer ΔV is less than 640 mps for an OSO true anomaly from 137 to 171 degrees. This corresponds to a CSM transfer angle range of 130 to 160 degrees and an OSO phasing angle range of 125 to 160 degrees.

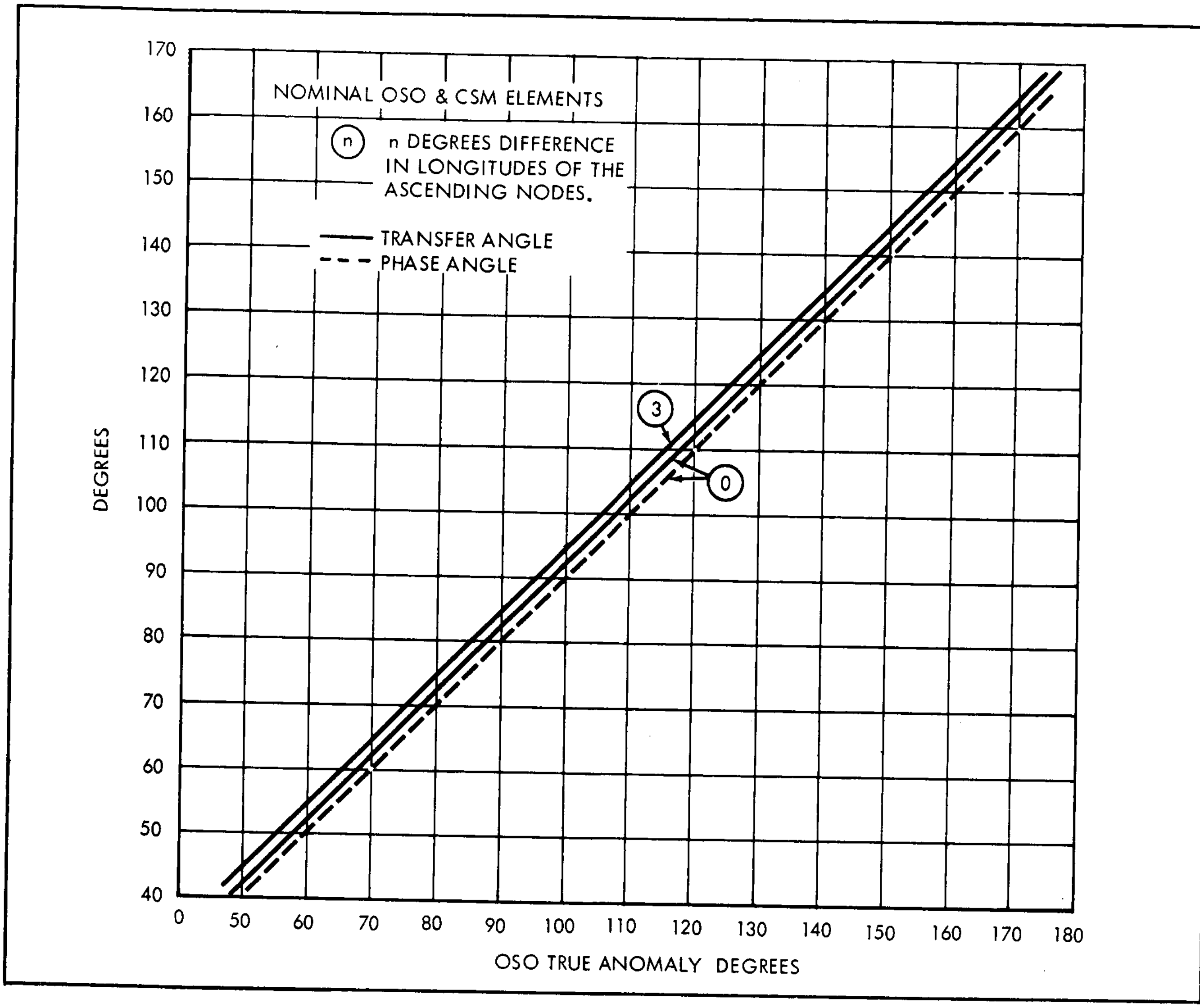

Fig. 3-5 Out of Plane - Angle Relationships

The time of transfer can be related to the OSO true anomaly at transfer and the $\Delta\Omega$ of the orbits. However, because the $\Delta\Omega$ being considered are very small, the transfer times versus the true anomaly relation in all the orbits of interest will be very close to that illustrated in Fig. 3-6 for $\Delta\Omega=0^{\circ}$.

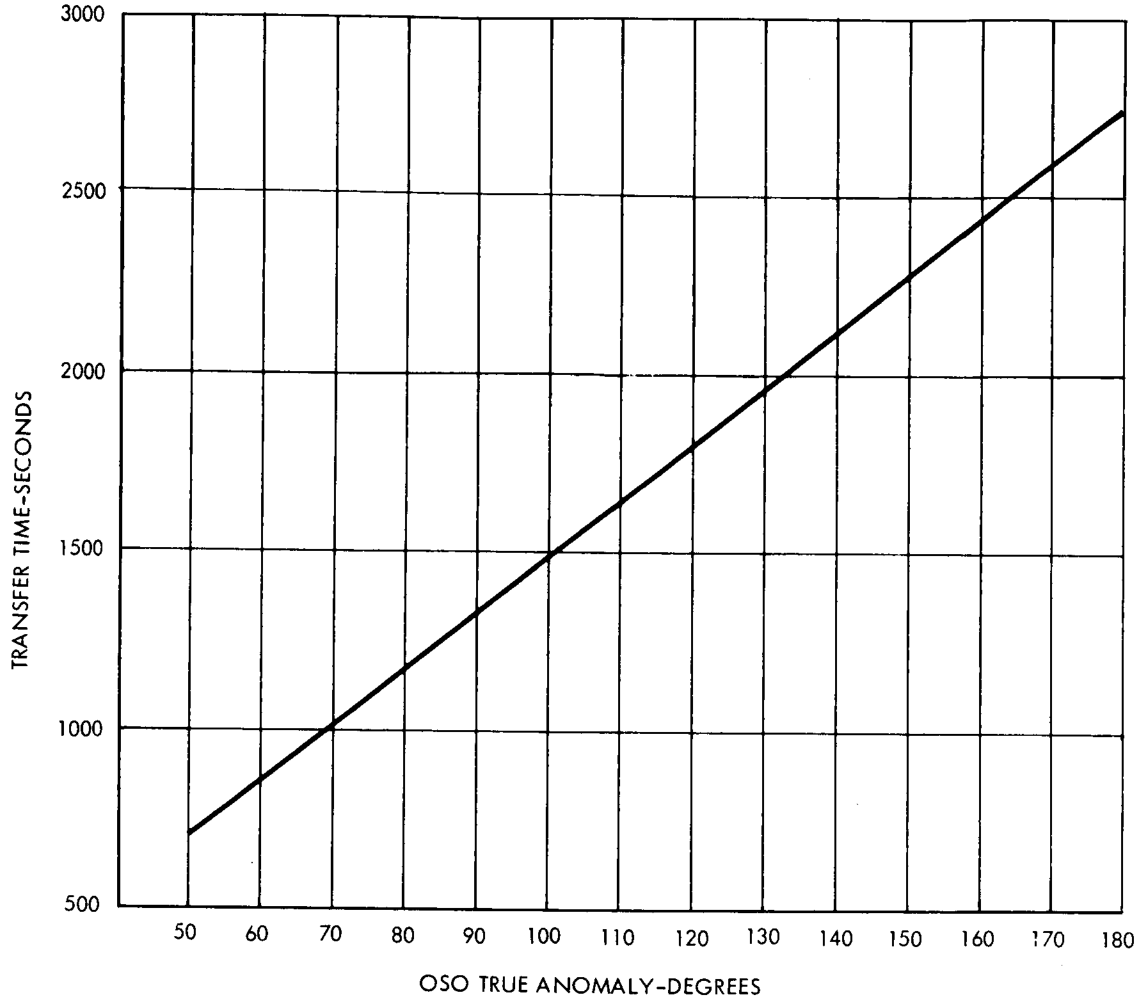

Fig. 3-6 Out of Plane - Time to Transfer

Variation of OSO Eccentricity and Inclination. The effect of variations in the OSO orbit elliptical elements were determined by holding constant all the CSM orbit elements, the semimajor axis, the longitude of the ascending node, and the argument of perigee of the OSO orbit. First, the eccentricity, and then the inclination of the OSO orbit were separately varied over the ranges specified in the constraints.

The ΔV required for an out of plane transfer as a function of the difference in longitudes of orbits was determined. Table 3-1 gives the average and maximum values of the change in ΔV brought about by varying OSO elements Δe and Δi. The effects are based on holding the semimajor axis of the transfer ellipse constant. The average values are found in the region of the acceptable transfer angles noted above. It was noted that whenever the difference in inclination of the two orbits was decreased, the ΔV requirement decreased.

Table 3-1
EFFECT OF OSO ELEMENT VARIATIONS
(Nominal CSM Orbit Elements)

OSO Element Variations	ΔΩ	Average Change (mps)	(fps)	Maximum Change (mps)	(fps)
Δe = ±0.002 (i = 32.850 deg)	0	∓7.3	∓24.2	∓21	∓68.8
	1	∓9.8	∓32.1	∓24	∓78.7
	2	∓9.8	∓32.1	∓25	∓81.9
	3	∓7.6	∓24.9	∓23	∓75.4
Δi = ±0.1 (e = 0.004)	0	±14	±45.9	±16	±52.4
	1	±13	±42.7	±14	±45.9
	2	±12	±39.3	±12	±39.3
	3	±12	±39.3	±12	±39.3

The aforementioned data indicates that the anticipated variations in the OSO orbit will not significantly change the required total ΔV for rendezvous.

Variation of CSM Eccentricity and Inclination. The change in the velocity increment required for transfer with variations in the elliptical elements of the CSM parking orbit was determined. The OSO orbit elements were held at their nominal values, as were the semimajor axes, the longitude of the ascending node, the argument of perigee, and the mean anomaly of the CSM orbit. The eccentricity and inclination of the CSM parking orbit were then varied individually over the specified variations from the nominal. The average increase, or decrease, in ΔV required with reference to the nominal ΔV are presented in Table 3-2.

Table 3-2
EFFECT OF CSM ORBIT ELEMENT VARIATIONS
(Nominal OSO Orbit Elements)

CSM Element Variations	ΔΩ	Average Change from Nominal (mps)	(fps)
Δe - ±0.00021 (i = 28.5 deg)	0	±2.4	±7.87
	1	±2.7	±8.84
	2	±2.7	±8.84
	3	±2.4	±7.87
Δi = ±0.008 degs (e = 0.00024)	0	∓1.2	∓3.93
	1	∓1.2	∓3.93
	2	∓0.9	∓2.95
	3	∓0.9	∓2.95

The change in ΔV for a specific eccentricity and ΔΩ have been reasonably constant, and the deviations from about the average value presented above are very small. The magnitude of these changes in ΔV compared to a nominal ΔV of 640 to 760 mps are quite low and will not significantly effect the rendezvous.

Variations of CSM/OSO Orientation Elements. The following variations indicate that the arbitrary orientations of the perigee points of the two orbits and the mean anomaly of the CSM can be shown to have a small effect on the ΔV consumption in the transfer.

The CSM orbit is essentially circular. At the extreme of its probable eccentricities (e = 0.00045), the variation of the orbital velocity is on the order of ±3.4 mps from the nominal circular orbit velocity. Thus, various orientations of the perigee point will introduce a negligible variation in the total ΔV requirement for a transfer. To prove this, the elements of OSO were held at their nominal values, as were the eccentricity, the inclination, the longitude of the ascending mode, and the semimajor axis of the CSM orbit. The position of the perigee point and the position of the CSM were varied so that the sum of the argument of perigee of the CSM and the mean anomaly of the CSM in its orbit were constant. This resulted in variation of only ±3 mps (9.8 fps) around the nominal case.

The OSO orbit has a noticeable eccentricity. This leads to a variation of ±46 mps (150 fps), about the circular velocity in the extreme elliptic case (e = 0.005), and ±30 mps (98 fps) in the nominal case (e = 0.004). Points near the apogee of OSO require more ΔV to be reached in a comparable trajectory than do points near the perigee. This offsets the saving in ΔV since an OSO moves more slowly at apogee than perigee. Consider holding the elements of the CSM and OSO orbits except for the argument of perigee of the OSO orbit, at the nominal values. Shifting the perigee point results in negligible saving, or loss, of ΔV as compared to the nominal case. The main effect is to shift the transfer angle corresponding to minimum ΔV toward or away from 180 degrees. In all cases, the minimum ΔV is essentially the same.

3.2.2 Plane Change/Coplanar Transfer

This approach divides the transfer into two independent maneuvers: (1) a plane change by the CSM, and (2) a coplanar ascent to OSO. The CSM performs a plane change at the altitude of its parking orbit so that its plane is coincident with the plane of OSO. Following the plane change, the CSM performs a coplanar transfer to the orbit of OSO. The ΔV required for the plane change is a function of the inclination of the CSM parking orbit and the difference in longitude of the ascending nodes of the OSO and CSM orbits. The ΔV for the coplanar transfer (Fig. 3-7) depends on the semimajor axis of the transfer ellipse, the eccentricities of the OSO and CSM orbits, and the difference in the perigee points of the two orbits.

Plane Change. The ΔV required for the CSM plane change is a function of the angle between the planes of the two orbits. The plane change angle is composed of the differences in inclinations (Δi) of the two orbits, and the differences in the longitudes of the ascending nodes (ΔΩ) of each orbit. As illustrated in Fig. 3-8, thrust impulse is required to change the CSM velocity vector from an orbital inclination of 28.5 degrees to an inclination of 32.85 degrees. Figure 3-9 presents ΔV requirements as a function of plane change. It can be seen that a Δi of 4.35 degrees, (i.e., CSM at 28.5 degrees inclination) requires 583 mps (1900 fps). Added to this is the ΔV requirements to compensate for any differences in the longitude of the ascending nodes. Figure 3-9 also shows the ΔV versus the difference in longitude for several inclinations of the CSM. As the inclination of the CSM approaches that of OSO, the plane change requires less ΔV; this indicates the advantage of launching the CSM in the plane of OSO.

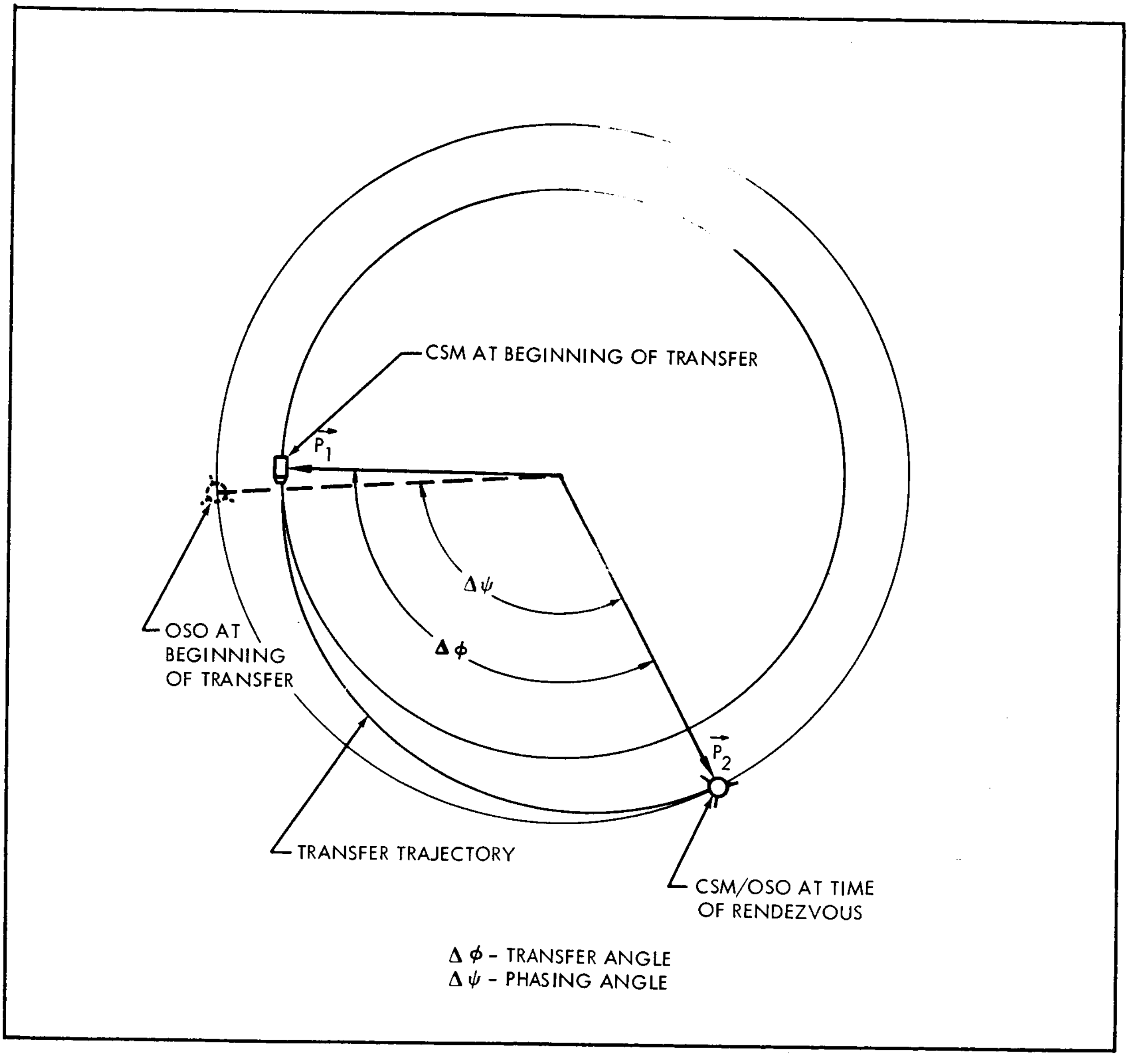

Fig. 3-7 Coplanar Orbital Transfer

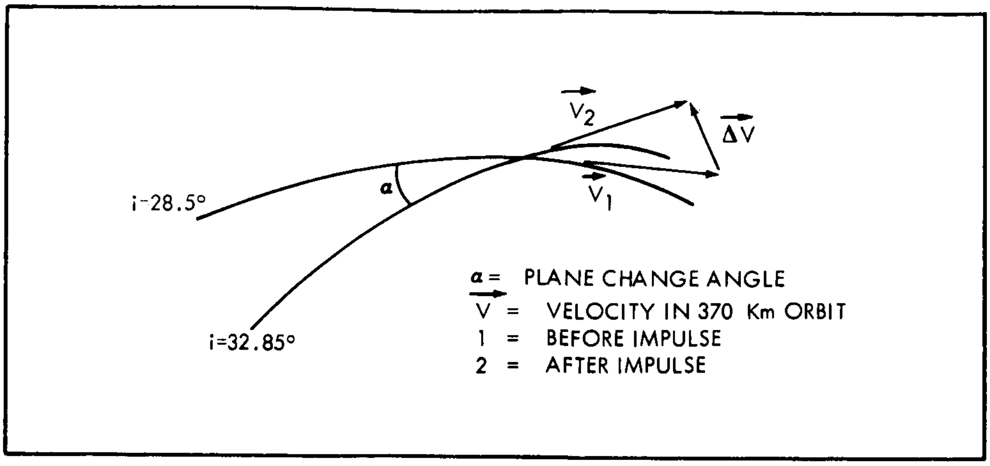

Fig. 3-8 Plane Change Vector Relationships

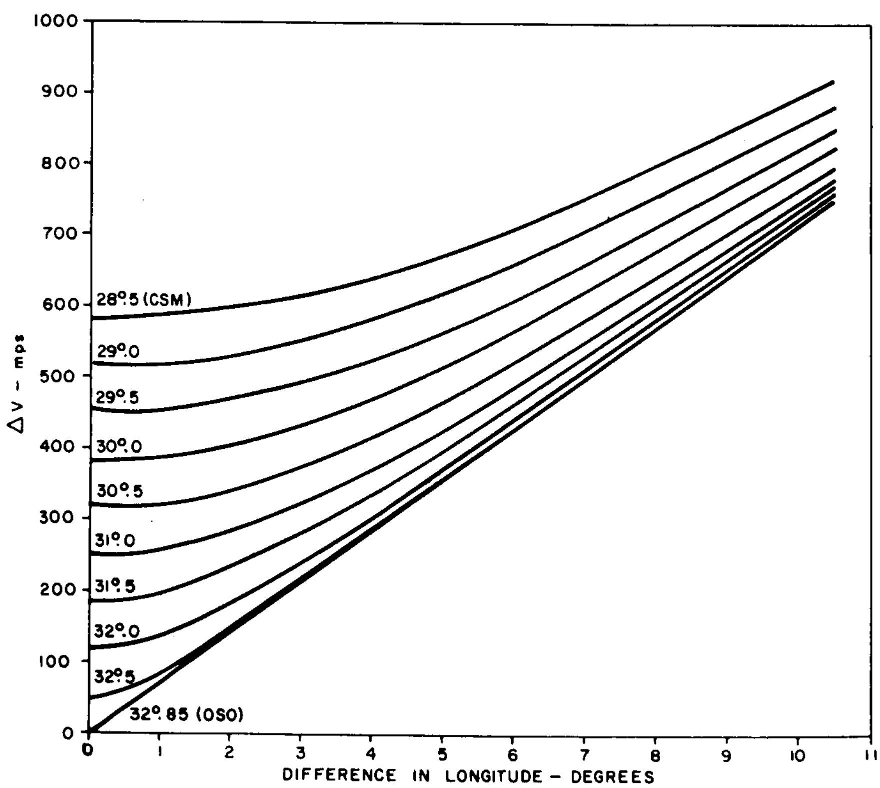

Fig. 3-9 ΔV Requirements as a Function of Plane Change

Coplanar Transfer. Consider next the coplanar transfer following a plane change at 370 kilometers. This transfer can be considered as a minimum energy case, based on a Hohmann transfer in which the impulse initiating the transfer is applied tangentially at the perigee of the transfer ellipse. The minimum eccentricities are used in this case, so that both the CSM and OSO orbits are nearly circular. The minimum ΔV value of 115 mps (380 fps) for a transfer angle of 180 degrees was determined; this is shown in Fig. 3-10. In this transfer, the total ΔV is on the order of 213 mps (700 fps), or less, if the CSM transfer angle is between 120 and 240 degrees.

A ΔV requirement of 698 mps (2300 fps) is required for a rendezvous based on a 4.35 degree plane change at 583 mps and a coplanar ascent at 115 mps. With a ΔV allowance of 762 mps, only an increment of 64 mps would be available for correcting longitude differences, terminal closure, and close-in maneuvering. The rigid timing in terms of launch and phasing required for this transfer mode is indicative of the desirability of an initial CSM launch into the nominal OSO orbit inclination and a subsequent coplanar orbital transfer.

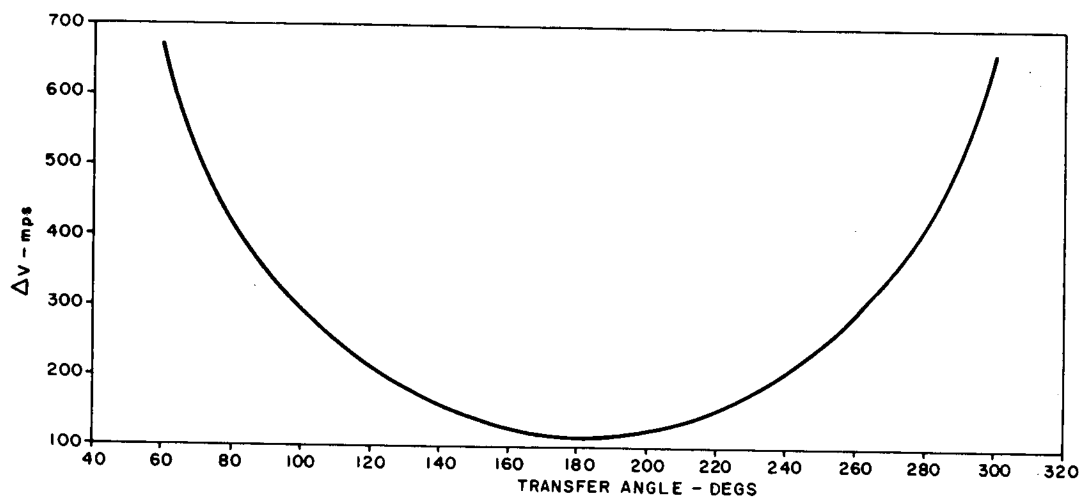

Fig. 3-10 In-Plane, Minimum Energy Transfer

Coplanar Phasing. The oblateness of the earth causes the orbits of the CSM and OSO to have a nominal precession westward of 7.18 and 6.17 degrees per day, respectively. The CSM orbit plane approaches that of OSO at a rate of 1.01 degrees per day. This precession can be used to match the longitude of the ascending nodes of the two orbits. The greatest portion of the ΔV for any rendezvous mission will be consumed in the plane change (i.e., 583 mps required for a Δi of 4.35 degrees). If the CSM inclination can be made to approximate that of the OSO, the ΔV requirements will be much smaller. This will allow for a greater flexibility in the ascent, and also permit a wider launch window.

3.2.3 Coplanar Transfer

The coplanar transfer starts with the CSM in a 370 kilometer altitude parking orbit which coincides with the OSO orbit. The analyses of the coplanar transfer in the preceding paragraphs also apply to this maneuver.

Factors Affecting ΔV Requirements. There are many factors which contribute to the ΔV requirement for a given orbital transfer. Besides the eccentricities of the OSO and CSM orbits previously discussed, there are also the semimajor axis and eccentricity of the transfer ellipse, and also the difference in the location of the perigee points of the two orbits. Given two position vectors, there are a number of trajectories of varying semimajor axes and times of transfer all of which can be within the allowable ΔV budget. Consider a typical case where all elements of OSO and the CSM are the nominal. The ΔV requirement as a function of the semimajor axis of the transfer ellipse is given in Fig. 3-11. The transfer times vary between 2137 seconds and 2013 seconds. This corresponds to phasing angles for OSO before rendezvous between 133.6 and 127.0 degrees. The difference of 6.6 degrees and transfer times permits a reasonable amount of flexibility with respect to OSO phasing.

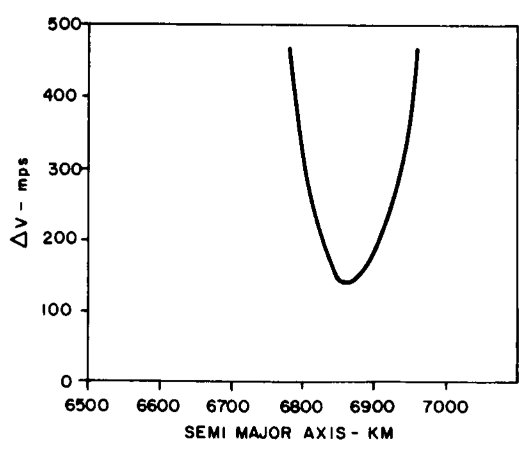

Fig. 3-11 ΔV for Transfer Angle of 132 Deg.

Variation of OSO/CSM Perigee Points. In all coplanar transfers, the inclinations and the longitudes of the ascending modes of the two orbits are identical. In this part of the analysis, the eccentricities of the two orbits are taken at their nominal values. The argument of perigee and the mean anomaly of the CSM position are chosen arbitrarily. The angle between the radius vectors to the perigee points are then varied.

The effect of varying the angle between the perigee points for the OSO and CSM is given in Fig. 3-12, as a function of degrees of transfer angle. The minimum ΔV for each transfer angle shifts in terms of $\Delta\omega$, the angle between the perigee points.

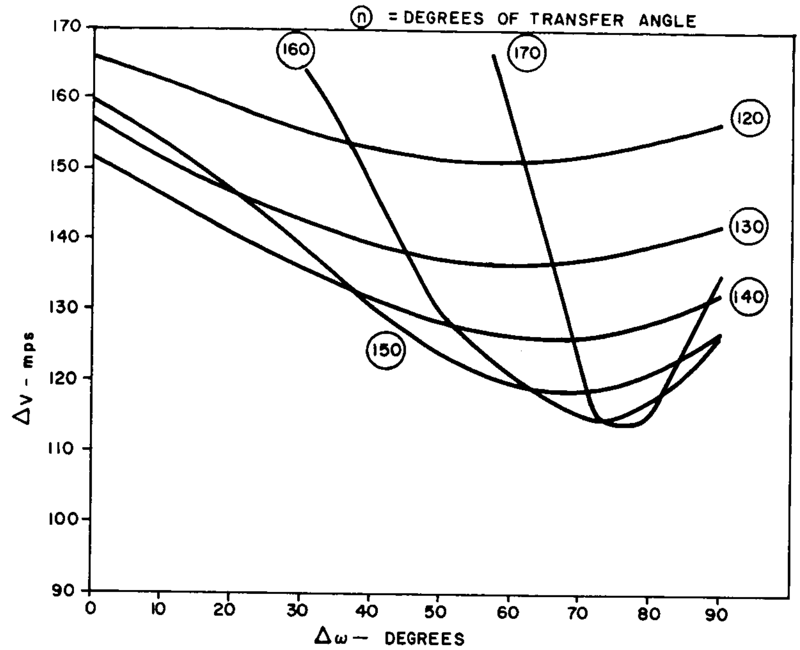

Fig. 3-12 ΔV Variation vs. Orbit Orientation - Coplanar

Variations of CSM Position. The position of the CSM in its orbit at the start of the transfer has an affect in the ΔV required for the transfer. For this part of the analysis, the eccentricities of the orbits of OSO and the CSM were held at the values in the nominal cases as were the respective arguments of perigee and semimajor axes. The position of the CSM in its orbit at the moment the transfer was initiated was varied by varying the mean anomaly. The length of the semimajor axis of the transfer ellipse in each case was held constant. This procedure has the effect of shifting the transfer angle at which minimum ΔV occurred. In all cases, there will be a curve similar to Fig. 3-13. A representative angular range of ±40 degrees was centered on an angle corresponding to a minimum ΔV. This minimum shifts to within the range of 130 to 150 degrees within the angular range, the ΔV requirement is on the order of 230 mps (750 fps).

Typical Transfer. Consider a typical case of a coplanar or in-plane transfer. Fig. 3-13 gives the ΔV for the transfer as a function of the transfer angle for a representative semimajor axis of the transfer ellipse. Here, a minimum ΔV of 140 mps (460 fps) occurs when the transfer angle is approximately 145 degrees. At a transfer angle range of 145 ±15 degrees, the ΔV requirement is less than 152 mps (500 fps). Since the orbits are nearly circular, each 10 degrees of transfer angle is equivalent to 160 seconds of transfer time.

In all of the examples considered for coplanar transfer, there are many possible orbit transfers where the ΔV requirement is well within the allowable ΔV budget.

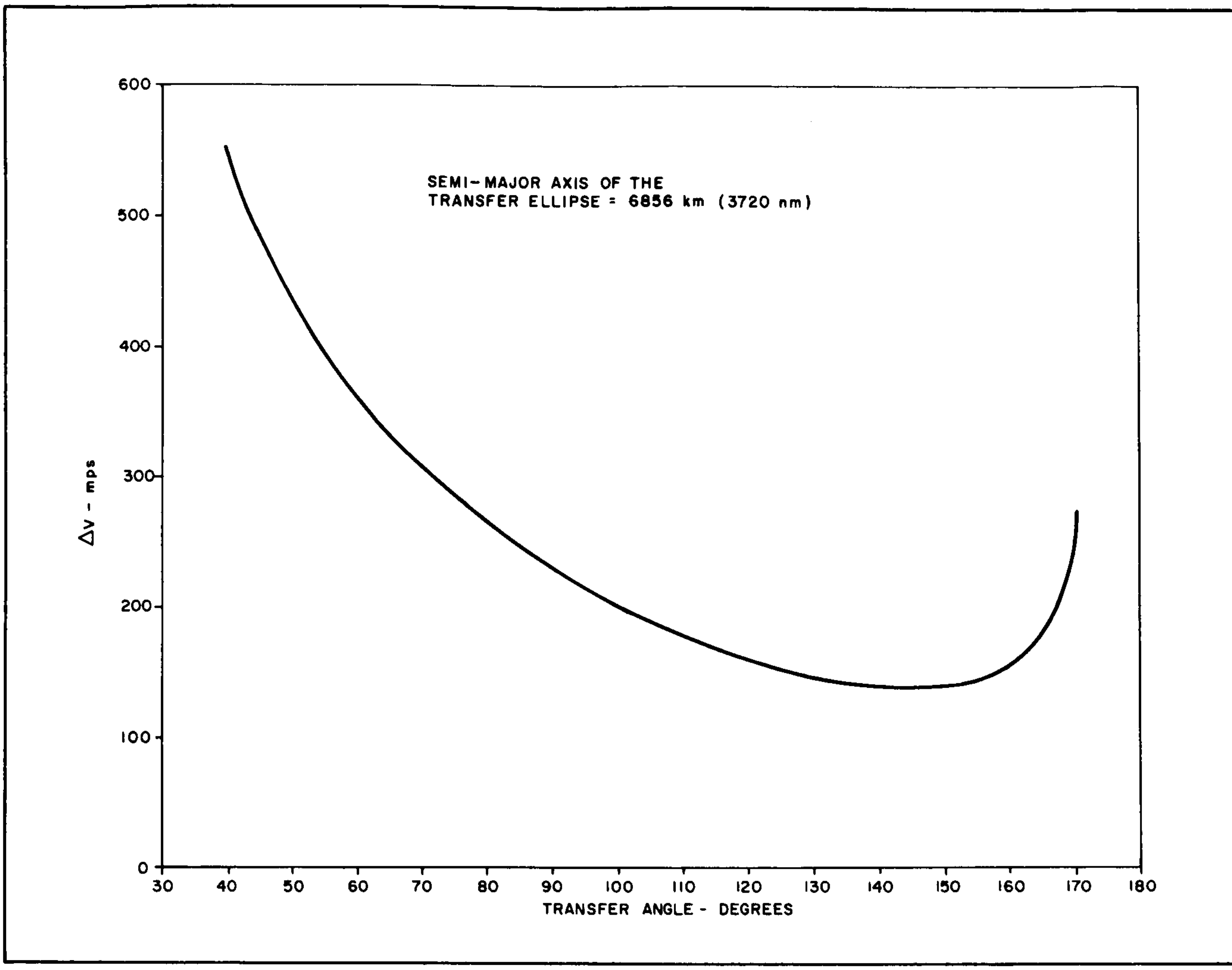

Fig. 3-13 ΔV for Coplanar Transfer

3.2.4 Launch Windows

If the CSM is launched as the launch site moves through the orbital plane of OSO, a parking orbit in the plane of OSO can be established. However, if the vehicle is launched before or after the in-plane launch opportunity, the longitude of its orbital plane will not coincide with that of OSO, and an additional velocity expenditure will be required. The launch window is the time span about the in-plane launch opportunity during which the vehicle can be launched and a plane coincident with the OSO orbit plane achieved. When an in-plane launch cannot be achieved, within a specific ΔV budget, the plane change angle can be minimized by launching the CSM to intercept the OSO orbit plane 90 degrees down range from the launch site.

In this discussion, the Apollo CSM launching site is at latitude of 28 degrees, 34 minutes. The launch window, as a function of ΔV required, and the plane change angle is given in Fig. 3-14. Within a span of 175 minutes, the required velocity change does not exceed 134 mps (440 fps).

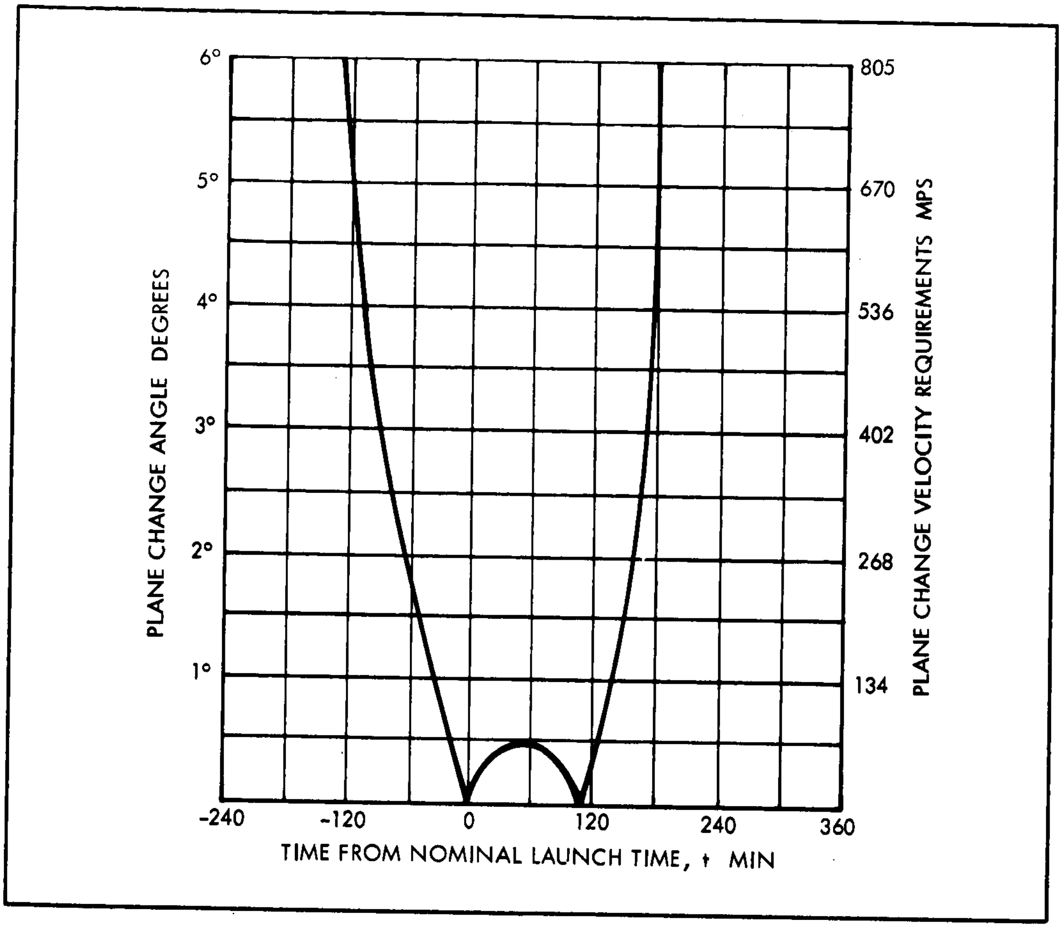

Fig. 3-14 Launch Window

The plane change may need to take out only a portion of the delta longitude between the actual plane of the CSM orbit and the necessary plane. Differential precession of the orbital planes can remove the rest of this difference.

3.3 TERMINAL CLOSURE

A terminal closure maneuver is required to connect the position uncertainties and transfer errors which may be present in the rendezvous transfer trajectory. The source and magnitude of these uncertainties and errors are discussed below. Sensors to provide terminal guidance data are reviewed and the visibility of OSO is analyzed to establish the feasibility of using simple optical sensors. Intercept and pursuit course closure maneuvers are analyzed and a terminal closure procedure is recommended.

3.3.1 Position Uncertainties

The principal uncertainty will be the position of the passive OSO. Satellite information concerning its orbit will be derived from visual observations and radar skin tracking during passage over the tracking networks. The position of the passive OSO should be known to within the following accuracies:

- Longitudinal: ±1.3 km (0.77 nm)
- Cross Range: ±0.4 km (0.22 nm)
- Radial: ±0.4 km (0.22 nm)

Since the CSM is an active satellite, its position will be known to ±300 meters (980 feet) in longitude and ±150 meters (490 feet) cross range and radial. Since this uncertainty is considerably less than the OSO uncertainty, the CSM position will be a secondary source of error.

The total errors resolved in the longitude, cross range, and radial components due to a passive OSO positional uncertainty, a CSM positional uncertainty, and residual errors from a transfer thrust can be combined by a root mean square method to obtain a total uncertainty of:

- Longitude: ±1.6 km (0.87 nm)
- Cross Range ±0.5 km (0.27 nm)
- Radial: ±0.5 km (0.27 nm)

3.3.2 Transfer Error

The principal source of error will be introduced during the application of the transfer initiating thrust. These specific sources of error are:

- A difference in velocity from that actually required
- A difference in position from the theoretical position
- A misalignment of the thrust vector
- A timing error

Changes in the radial position vector and the velocity of CSM at the time of transfer cause a change in the semimajor axis of the transfer ellipse, and consequently in the mean motion of the period and in the argument of perigee. Thrust misalignment will be reflected in error in the true anomaly in the orbit. A timing error will cause a change in the argument of perigee. An initial position error of 1 kilometer (0.54 nautical mile) and a velocity error of 1.5 mps (4.9 fps) will produce a total position error at the completion of transfer of 8.4 kilometer (4.5 nautical mile). One, or a series, of corrective thrust(s) during ascent would remove most of the transfer thrust errors at a cost of less than 6.1 mps (20 fps).

Another source of error occurs in the circularization thrust at the completion of transfer. The CSM will be in sight of OSO and on the order of only 152 meters (500 feet) below. Therefore, these errors will be removed during the transfer to the night time station keeping position.

These rendezvous transfer errors can be combined in a root-sum-square manner to yield a maximum position uncertainty of ±8.4 kilometer (4.5 nautical mile) longitude at the completion of nominal rendezvous. This error will be biased along the longitude direction; radial and cross range errors will be less than half the longitude error. These error values define a volume of uncertainty which is an ellipsoid of revolution. The longitude error represents the semimajor axis, and the radial and cross range errors represent the semiminor axes of this ellipsoid (Fig. 3-15). This volume of uncertainty can be interpreted with either the OSO or CSM at the centroid of the volume at rendezvous and with the other vehicle anywhere within the volume.

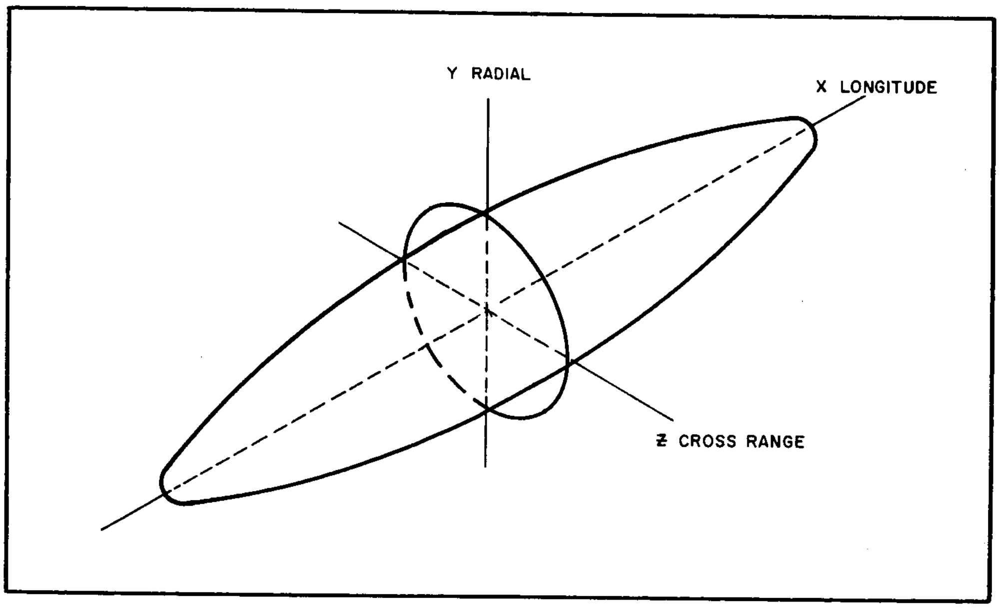

Fig. 3-15 Error Ellipsoid for Passive OSO

Trajectories of the CSM with respect to OSO were computed for longitude and radial errors. This analysis used conservative values of ±10 kilometer (5.4 nautical miles) longitude and ±5 kilometer (2.7 nautical mile) cross-range errors, and it assumed a minimum energy transfer to OSO in a circular orbit. The trajectories for the maximum error values and no error are presented in Fig. 3-16. During much of the transfer, the trajectories will be similar; the line of sight, (LOS), between an inertially stabilized CSM and the OSO varies slowly over a limited range until the final position of the transfer, (Figs. 3-17, and 3-18). The out of plane error can be analyzed independent of the coplanar error. At a maximum cross range error of ±5 kilometer (2.7 nautical mile), the cross range velocity component will be about 1 mps (3.28 fps) away from the OSO.

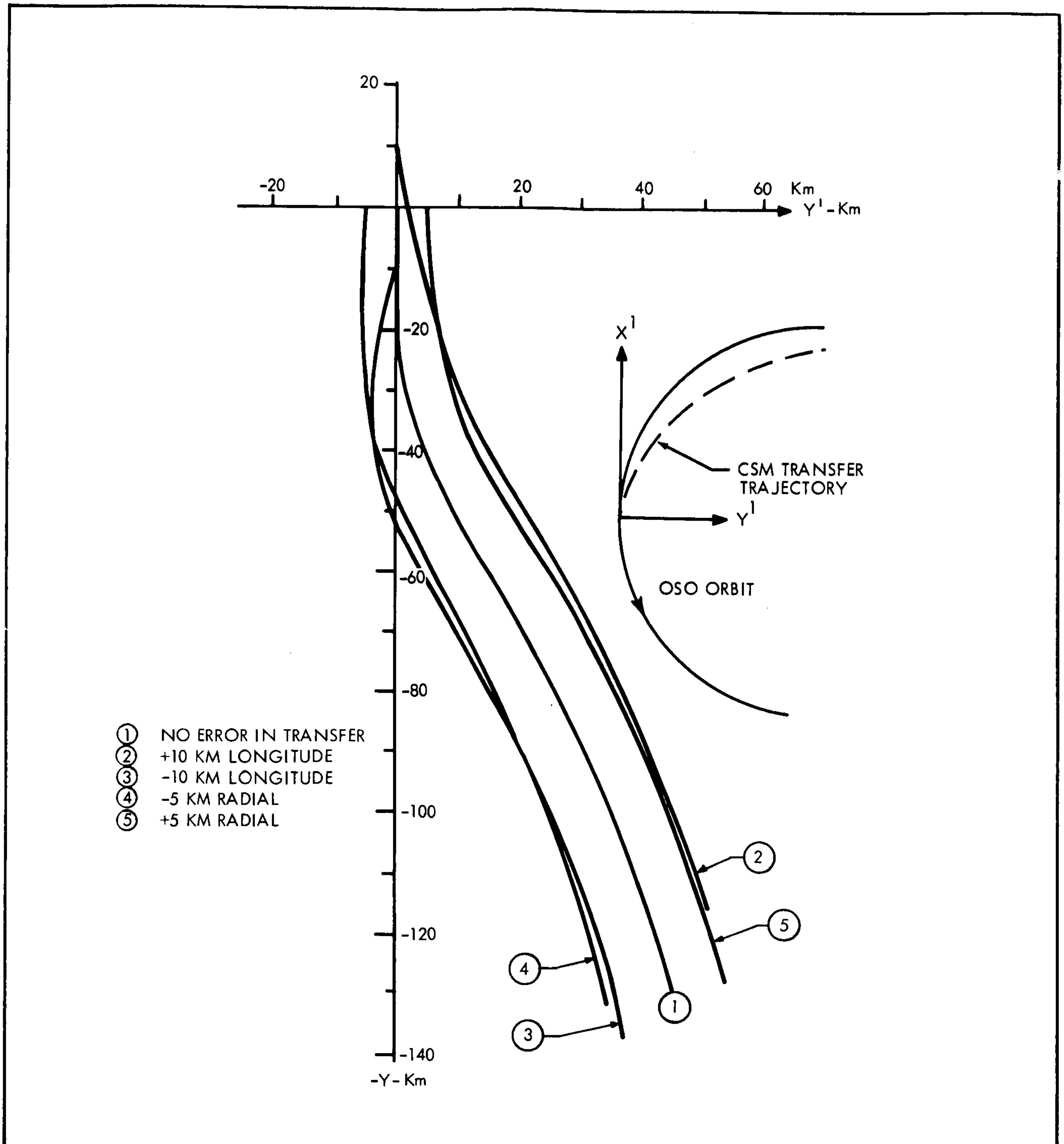

Fig. 3-16 CSM Rendezvous Trajectories (Inertially Oriented Coordinates)

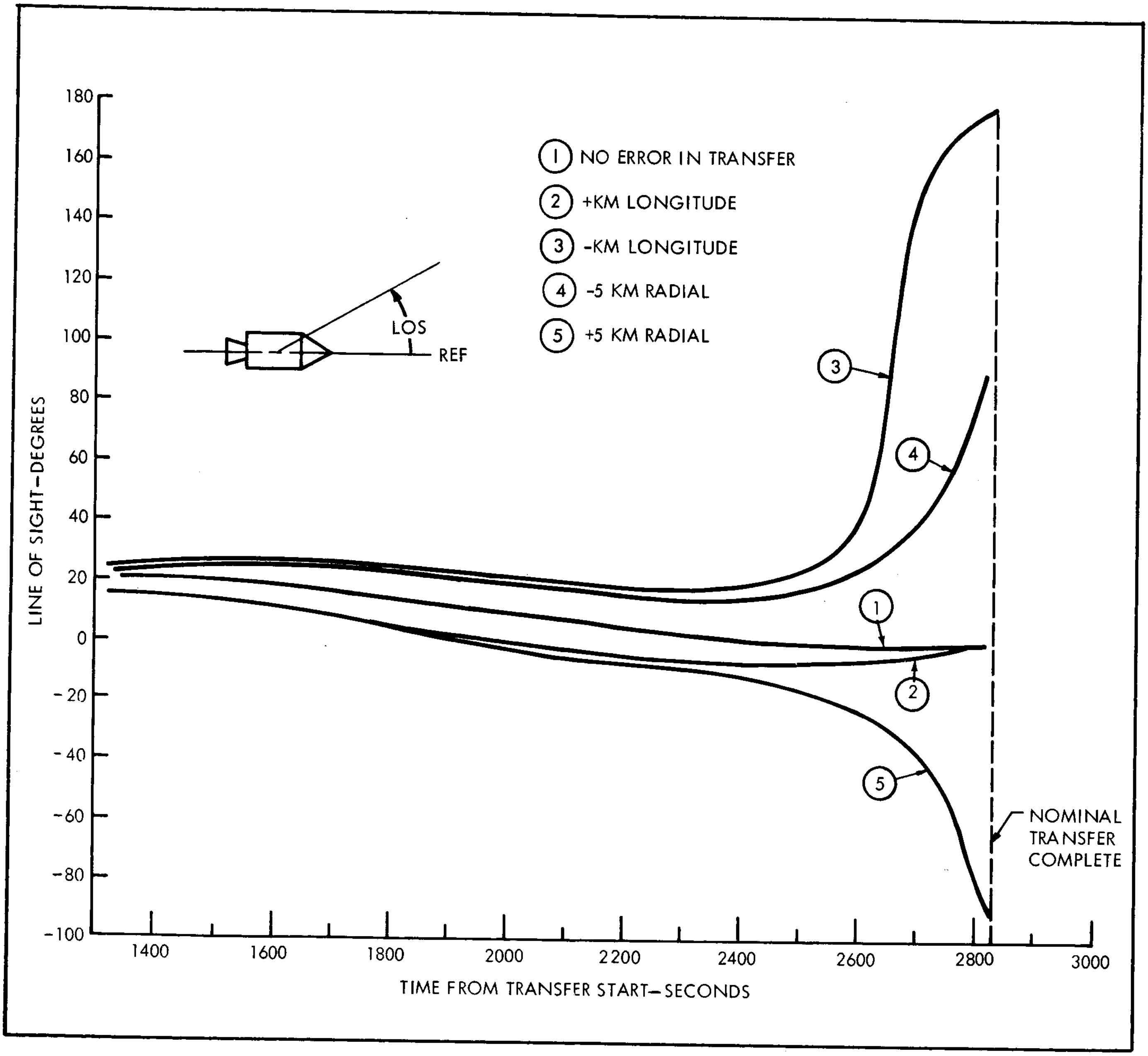

Fig. 3-17 Line of Sight, CSM to OSO

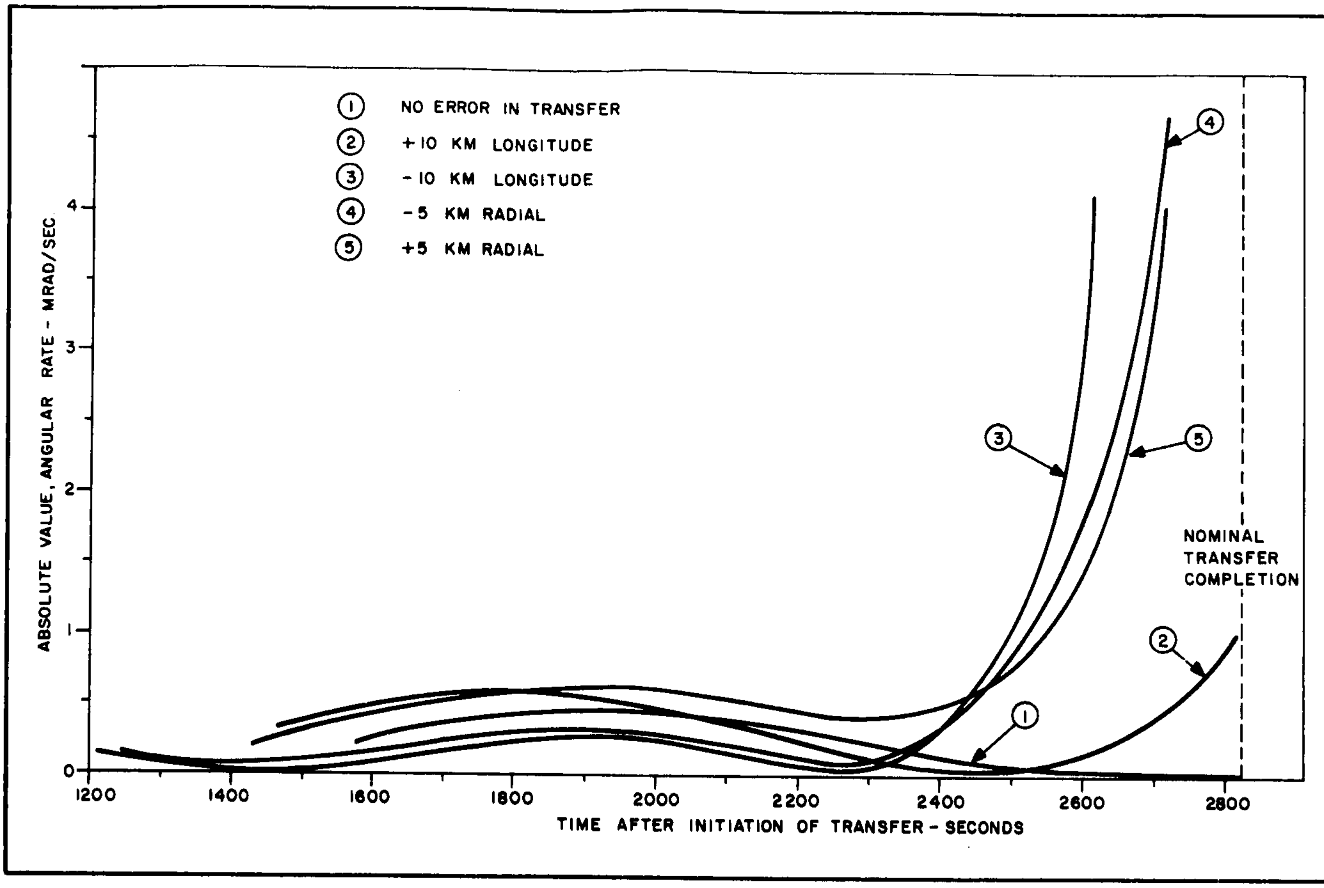

Fig. 3-18 Line of Sight Rate, CSM to OSO

The analyses indicate that the range, range rate, angle, and angle rate of the CSM with respect to the OSO will vary between narrow limits during much of the transfer. This apriori information can be used to identify the performance requirements of a terminal guidance system.

3.3.3 Terminal Guidance

A terminal guidance sensor installed in the CSM could provide data to compute corrections for both position and trajectory errors. Such a sensor must be able to acquire and track a noncooperative OSO since an inactive OSO will not be transmitting RF signals that could be used for acquisition and tracking. A number of noncooperative terminal guidance sensors were reviewed to determine their applicability for this mission; these are presented in Table 3-3. The passive optical long wave infrared (LWIR) sensors only provide angle and angle rate information; however, approximate range and range rate data can be determined from angle information using the techniques described by Lineberry et al. (Ref. 1). The reflected sunlight optical systems require that the OSO be illuminated by the sun, preferably with the CSM between the sun and the OSO; the LWIR sensors perform best against a dark space background. In addition, both reflected sunlight and LWIR sensors can be impaired by an earth background. None of the sensors considered perform satisfactorily looking directly into the sun. The radar system offers the best capability for acquisition, while the higher frequency sensors (optical wavelengths) provide the best angle tracking. Therefore, for optimum capability, a hybrid system would be recommended. However, such a system requires considerable development; because of the apriori data that will be available, a sophisticated terminal guidance sensor is not considered necessary for OSO rendezvous.

Of all the sensors considered, only the reflected sunlight manual optical system has been flight proven. The feasibility of using flight proven hardware for terminal guidance depends on both the ability to visually detect OSO and the ability to use the optical data to effect rendezvous. These considerations are reviewed in the following paragraphs.

Table 3-3
TYPICAL NONCOOPERATIVE TERMINAL GUIDANCE SENSORS

Guidance Sensors	Direct Information				State of Art	Flight Proven	Rendezvous Constraints Imposed	Applicable to other Missions
	Range	Range Rate	Angle	Angle Rate				
Radar (skin tracking)	X	X	X	X	Yes	No	No	Yes
Long wave infrared (LWIR)			X	X	Under Adv. Devel.	No	No	Yes
Active optical	X		X	X	Under Adv. Devel.	No	No	Yes
Reflected sunlight (automatic)			X	X	Under Adv. Devel.	No.	No	Limited
Reflected sunlight (manual)			X		Yes	Yes	Yes	Limited
Hybrid	X	X	X	X	Under Devel.	No	No	Yes

3.3.4 OSO Visibility

When illuminated by the sun, the OSO will appear to an observer as a bright object moving against a star background. Reports by both astronauts and cosmonauts have indicated it is possible to see stars in daylight under proper light levels and angles (Ref. 2). The OSO will be readily visible at the start of the daylight portion of the orbit with the CSM between the sun and OSO. The apparent visual magnitude of OSO was computed using the formulae of Ref. 3 and is presented as a function of range in Fig. 3-19. The albedo of OSO which was required for this analysis was computed to be 0.4. The analysis also assumed the solar vector to be at an angle of 60 degrees to the viewing line of sight, and that only half of the light was transmitted through the CSM window. The minimum brightness viewing attitude, with the sail on end, is excessively conservative since the sail is expected to be rotating; this would increase the area of the OSO reflecting sunlight.

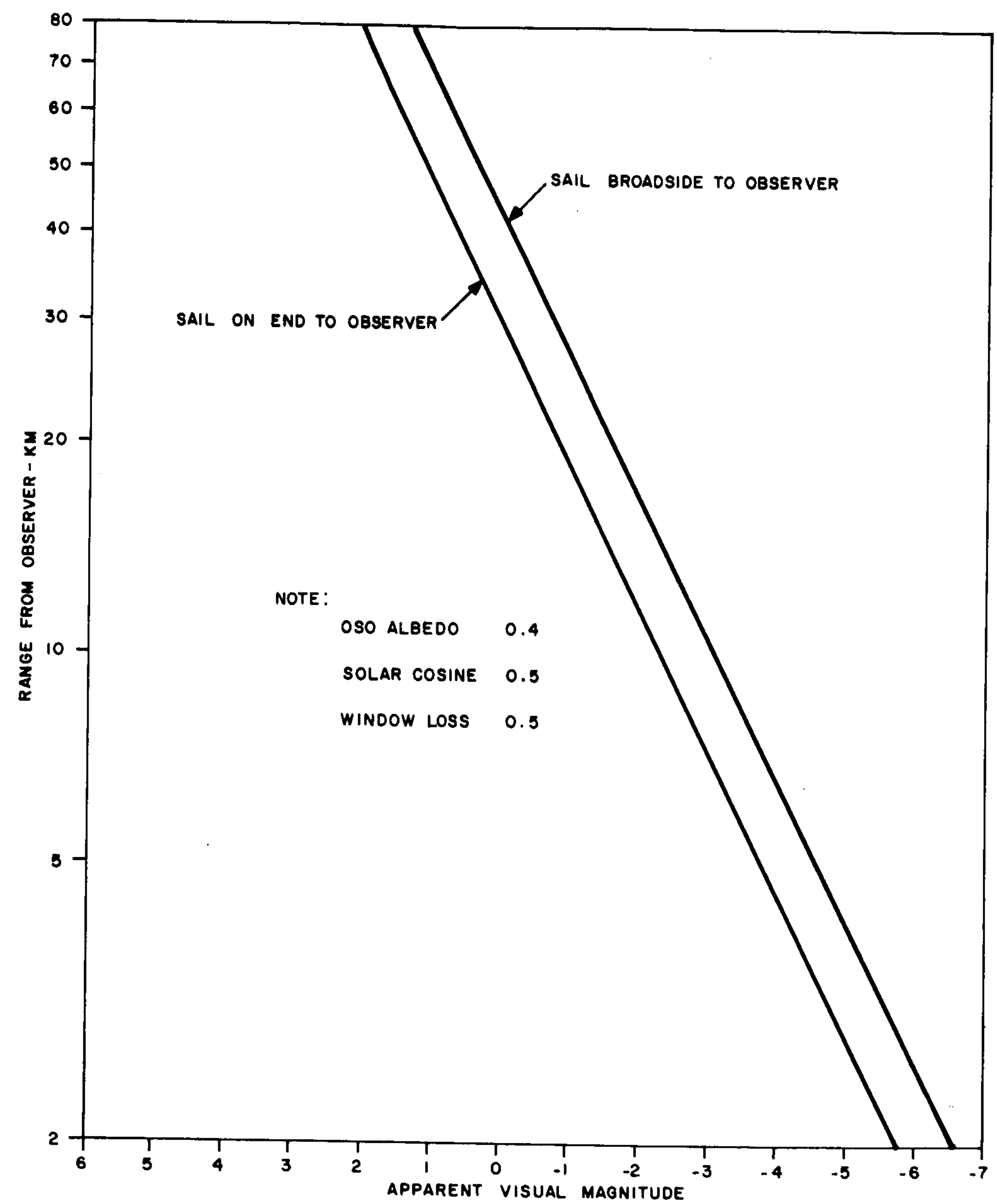

Fig. 3-19 Apparent Visual Magnitude of OSO

The OSO will appear very bright compared to the star background, Table 3-4. Even at 80 kilometer (43.4 nautical mile); it will appear as bright as many navigation stars. The ability to detect OSO will also be enhanced by its movement against the star background. Experiments described in Ref. 4 indicate man will have a 50 percent probability of detecting within 35 seconds a satellite of magnitude +3 moving against a memorized star field at 0.2 milliradians per second. At a relative movement of 1.6 milliradians per second, the 50 percent detection probability time was reduced to 20 seconds. A very conservative analysis of detection, using techniques described in Ref. 5 indicated the threshold of visibility of OSO to be about 60 kilometer (32.6 nautical miles) with a 97 percent probability of detection in 100 seconds.

Table 3-4
STAR DENSITY

Visual Magnitude	Total Number	Average Per Octant
-1.5 to +1.99	50	6.2
+2.00 to +4.00	480	60
+4.01 to +5.00	1090	136
+5.01 to +6.00	3230	404

Detection of OSO can be improved using a telescope with a reticle . Experiments have shown that a target of +3 magnitude moving at 0.1 milliradian per second, which was detected in an average of 169 seconds, could be detected in 35 seconds with an 833 line per inch reticle (Ref. 3).

This investigation has shown that it is possible to visually detect the OSO. Consideration of the rendezvous transfer trajectories and the most conservative visibility criteria indicates a 97 percent probability of detecting OSO with the unaided eye at a range of about 50 kilometers (27 nautical mile) approximately 1950 seconds after initiation of minimum energy transfer. The probability of detecting the OSO at 10 kilometer (5.4 nautical mile) increases to 0.999.

3.3.5 Closure Maneuvers

Three basic types of closure maneuvers were considered to correct rendezvous errors: (1) two-impulse trajectory, (2) pursuit course, and (3) intercept course. The two-impulse maneuver includes a corrective thrust application during transfer and a braking thrust at rendezvous. To compute the corrections requires range, range rate angle, and angle rate data. A pursuit course maneuver uses thrust normal to the line of sight (LOS) to maintain a constant LOS referenced to the local horizontal. Information to accomplish this maneuver includes a local horizontal reference, a target angle, and knowledge that the initial range rate is negative. The intercept course maneuver is similar to the pursuit course except the LOS angle is referenced to an inertial orientation. A braking thrust is required to null the relative OSO and CSM velocity after completion of all types of closure.

These closure maneuvers were begun during minimum energy transfers previously discussed in this section. These maneuvers can also be used with other transfers by varying the timing and the ΔV.

Accurate transfer trajectory data to compute mid-course corrections can be provided by Manned Space Flight Network (MSFN) tracking stations (Ref. 6). However, these corrections will only compensate for transfer trajectory errors and not for initial position errors since the later represent tracking network errors. This technique also requires that the transfer be made within range of MSFN tracking stations. If transfer is initiated after the CSM has been in a parking orbit for two or three revolutions, the MSFN will provide adequate coverage. However, for longer parking orbits, it will be necessary to schedule the transfer so the CSM can be tracked. This constraint may conflict with illumination requirements to maximize OSO visibility during transfer.

A mid-course correction to compensate for trajectory errors would require 6 mps (20 fps) correction and 58 mps (190 fps) for velocity matching. To correct for OSO position uncertainties would require less than 5 mps (16.4 fps) ΔV and an onboard means for determining the uncertainties.

Both pursuit and intercept course closure maneuvers were analyzed to determine the required velocity expenditure and the time to rendezvous (Ref. 7). The closure maneuver was assumed to start in the transfer trajectory and was completed when the CSM was at the OSO and their relative velocity nulled. The required velocity increment depends on the error in the initial transfer, and the time after initiation of the transfer that the closure maneuver is initiated as illustrated in Fig. 3-20. The pursuit course closure was found to require significantly more velocity expenditure than the intercept course maneuver. The velocities to effect rendezvous from the various trajectories approach a minimum about 2400 seconds after the start of transfer. At least 73 mps (240 fps) must be allowed for an intercept terminal maneuver with precise timing of the start of the maneuver; however, by allowing a ΔV of about 78 mps (256 fps), the maneuver could be initiated any time between 2300 seconds and 2550 seconds.

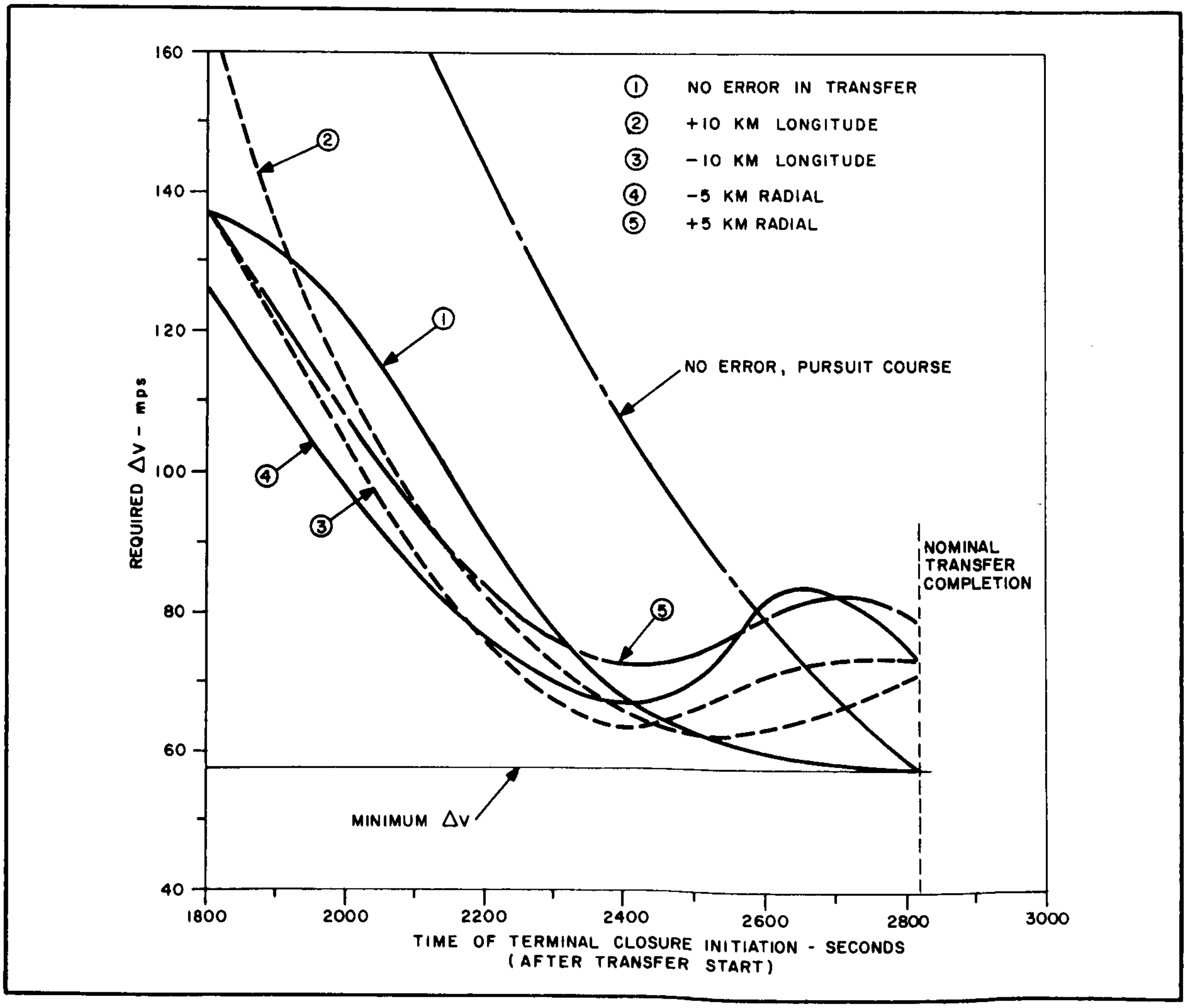

Fig. 3-20 Velocity Increment for Intercept Course Terminal Closure

The out of plane error must also be corrected. If the transfer is made from an initial coplanar orbit, a ΔV allowance of 4 mps (13.1 fps) can compensate for out of plane transfer errors.

With precise knowledge of the CSM and OSO positions and exact implementation of the transfer, 58 mps velocity increment is required to match the OSO and CSM orbits and thereby complete the transfer.

A reasonable assumption of a mid-course correction plus a position correction would be 69 mps (228 fps) and a transfer within range of tracking stations. An intercept course maneuver can be implemented with the reflected sunlight and manual on-board sensors for a velocity increment of 82 mps (269 fps).

The intercept course maneuver is feasible because the limits of error provide an apriori knowledge of the relative motion and position of the CSM. Although man cannot accurately judge the closing rate of the CSM to OSO, he can discriminate angular movement in the order of 0.1 milliradian per second. The trajectory calculations indicate that the range rate varies over a narrow limit between the possible transfer trajectories. For example, 24000 seconds after transfer, the range rate varies from -49 mps (160 fps) in the transfer with +10 kilometer longitudinal error, to -59 mps (195 fps) in the trajectory with a -5 kilometer radial error. The velocity matching thrust can be initiated for the minimum ΔV, and then the residual velocity can be manually nulled.

3.4 STATION KEEPING

Station keeping includes two distinct modes of operation, one for the night position of the orbit and the other for the day position of the orbit. During the night time mode, motion of the CSM and the separation between the CSM and OSO are selected to prevent a collision in the dark and yet not require excessive propellant to bring the CSM back to OSO. The daylight mode is a circumnavigation of OSO, so it can be inspected from all sides. To facilitate description of this motion, a new coordinate system was introduced. This new coordinate system and the station keeping maneuvers are described in the following paragraphs.

3.4.1 Coordinate System

The orbit of OSO is sufficiently circular to permit a simplification of the orbital mechanics calculations for the close-in maneuvers. The coordinate system used is centered on the center of mass of an ideal OSO as illustrated in Fig. 3-21. The X axis is tangent to the OSO orbit and positive in the direction of orbital motion. The Y axis is along the geocentric radial direction, and it is directed oppositely to the earth. The Z axis completes a right hand triad, and it is positive in the direction opposite to the angular momentum vector of the orbit. Since the OSO is considered to be in a circular orbit, the coordinate system is rotating at a uniform rate, with a period equal to the period of OSO. The theory of motion is two body. Atmospheric and earth oblateness affects are neglected. Considering the short time involved in a typical mission, this is an entirely acceptable procedure.

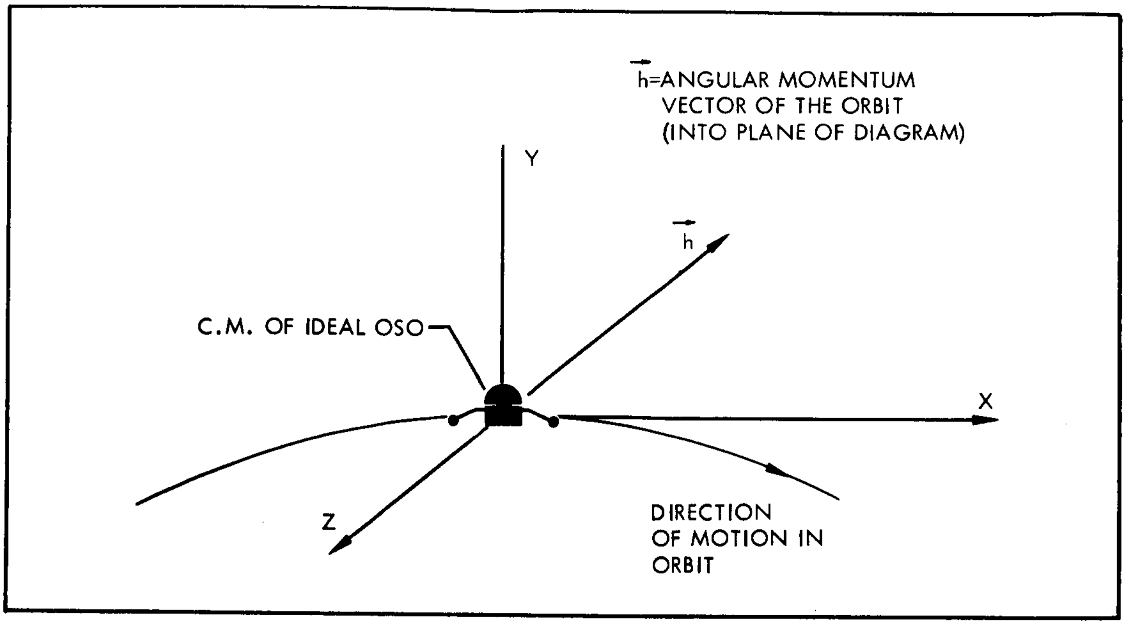

Fig. 3-21 Coordinate System for Close-in Maneuvers

The use of a rotating coordinate system requires a consideration of two accelerations: tidal and Coriolis. The tidal acceleration acts to separate OSO and the CSM if the CSM is displaced vertically from the X axis. Below OSO, the CSM will move ahead, and above OSO, the CSM will lag behind. The Coriolis acceleration works at right angles to the relative velocity vector of the CSM with respect to OSO. This causes the path of the CSM to curve. There is a change in the direction of the radius vector, but not the magnitude. Typical values of the accelerations are 2.5×10^{-4} mps (8.2×10^{-4} fps) and 1.5×10^{-3} mps (4.9×10^{-3} fps) for a tidal acceleration due to a displacement of 61 meters (200 feet), and a Coriolis acceleration due to a speed of 0.6 mps (2.0 fps), respectively. These accelerations are small and permit small relative velocities between the vehicles.

3.4.2 Night Time Station Keeping

There will be two periods of night time station keeping prior to docking with the OSO. During these periods, the CSM must stay reasonably close to the OSO so that an inordinate amount of fuel will not be required to bring the two vehicles close together when the new orbit day dawns. At the same time, the two vehicles must be adequately separated so that a night time collision cannot possibly occur.

The accelerations mentioned above cause a motion of the CSM in relation to OSO, whenever a vertical displacement of the CSM or a velocity difference exists. In the classical problem of station keeping, an ideal case, there is a match of the eccentricities of the orbits of the two vehicles and also of the periods. The CSM would be on the X axis directly ahead of OSO or directly behind for an indifinite length of time. In an actual case, the orbits are not perfectly matched. Thus, there will always be a y- displacement and/or velocity mismatch for which there must be compensation. The actual station keeping situation is dynamic. There will be an eventual drifting apart of the CSM from OSO. The only practical method for station keeping is to maintain distance by a thrust program. As discussed below, it is seen that the required station thrust is minimal.

In the philosophy incorporated in this study, the CSM is free to circumnavigate OSO during the orbital night. A volume is defined wherein the CSM is permitted to assume any position. An outer limit defines the maximum distance the CSM may be permitted to deviate from OSO, and an inner limit establishes a safe distance between the two vehicles (Fig. 3-22). The CSM is permitted to move under the influence of gravity alone until boundary is approached. The CSM then thrusts to maintain itself within the permissible limit. The thrust initiating this station keeping, and the following thrusts which maintain minimum distances are such, that the CSM is never swept toward the origin occupied by OSO. The station keeping can be maintained by a total ΔV of less than 0.6 mps (1.96 fps). The ΔV is dependent on the aiming angle of the thrust away from the limiting circle as presented in Fig. 3-23. The aiming angle is defined as the angle between the thrust vector and the tangent to the limiting circle at the position of the CSM. The night time station keeping can use a programmed thrust; if the moon is bright, it can be performed visually as has been demonstrated on one Gemini flight. Either way, the anticipated relative velocity is of the order of 0.3 mps (1 fps), which allows ample time for the crew to recognize difficulties and take corrective action.

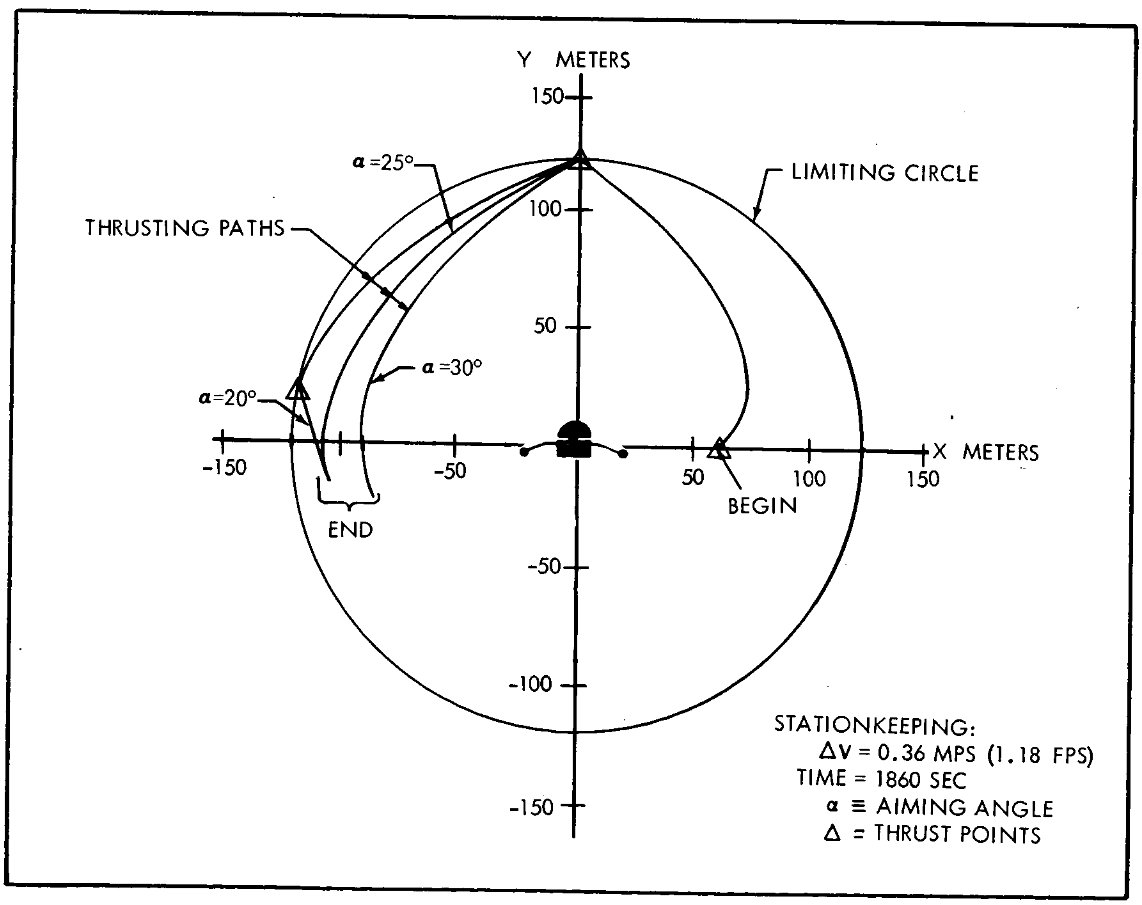

Fig. 3-22 Station Keeping Volume

α= AIMING ANGLE

α-DEGREES	ΔV- MPS	FPS
20°	0.42	1.38
25°	0.27	0.89
30°	0.30	0.98

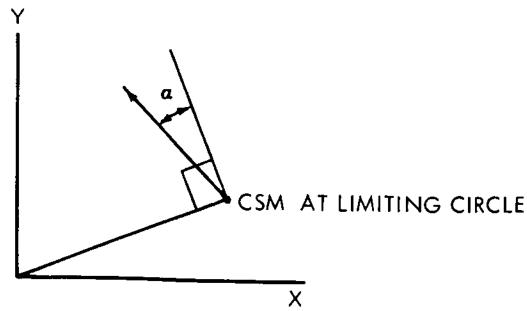

Fig. 3-23 Aiming Angle

3.4.3 Circumnavigation

Circumnavigation will take place on the day side of the OSO orbit to accomplish the following:

- Inspect for safety hazards from the target OSO
- Determine the rates of OSO rotation
- Decide on the most advantageous directions of approach to OSO for capture

Circumnavigation can be considered to consist of two independent motions. One is a motion within the X-Y plane, and the other is a motion in the Z direction. The Z component is necessary so that OSO may be viewed from all directions; it may be represented as an oscillation through the X-Y plane. The excursion of the CSM from the X-Y plane will begin at the X-Y plane with an initial Z component of velocity (Fig. 3-24).

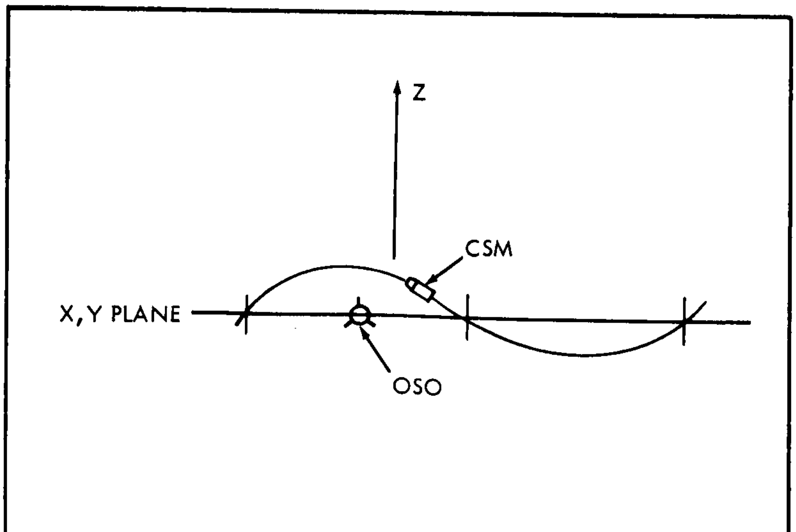

Fig. 3-24 Z - Component of Circumnavigation

A series of thrusts will then be applied until the CSM returns to the X-Y plane. The variables requiring consideration are the time required for each excursion, the greatest distance from X-Y plane reached by the CSM, and the thrust level applied to return the CSM to the X-Y plane. The thrust will be applied in a series of discrete impulses during the mission. Some representative values of Z components are given in Fig. 3-25. The ΔV requirements are on the order of 3 mps (9.8 fps).

OUT OF PLANE MOTION

CURVE	AVERAGE ACCELERATION		TIME FOR EXCURSION (SEC.)
	MPS^2	fps^2	
1	0.0003	0.0098	770
2	0.0006	0.0196	500
3	0.0009	0.0295	340

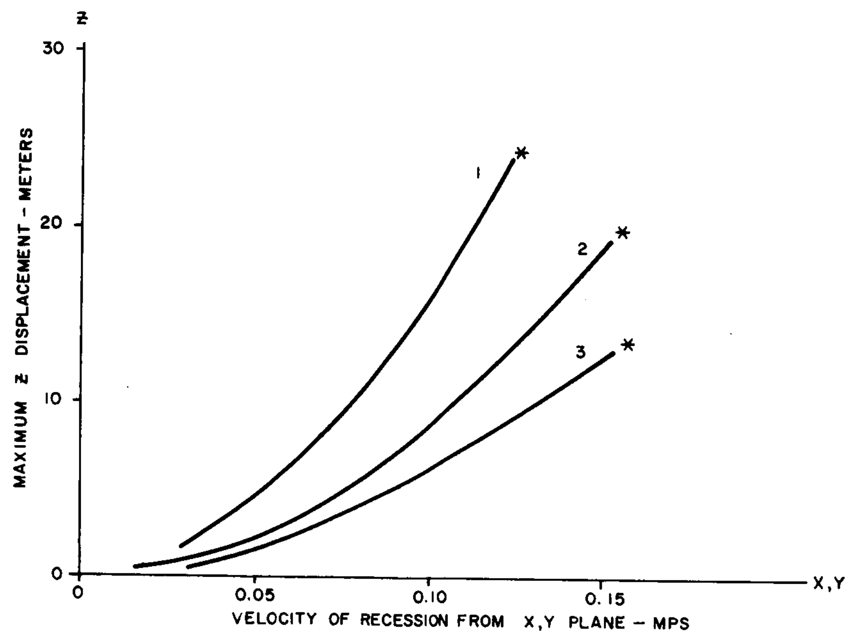

Fig. 3-25 Out of Plane Motion

The circumnavigation on the X-Y planes consists of a series of arcs intersecting a limiting circle about OSO. The ΔV requirement is a function of the speed and direction by which the CSM is required to recede to the limiting circle. An average velocity of 0.15 mps (0.5 fps) permits a reasonably low ΔV of about 1.8 mps (5.9 fps) total for a typical mission. The velocity in turn defines the number of revolutions of the CSM about OSO in the time allotted for this phase of the mission (Fig. 3-26).

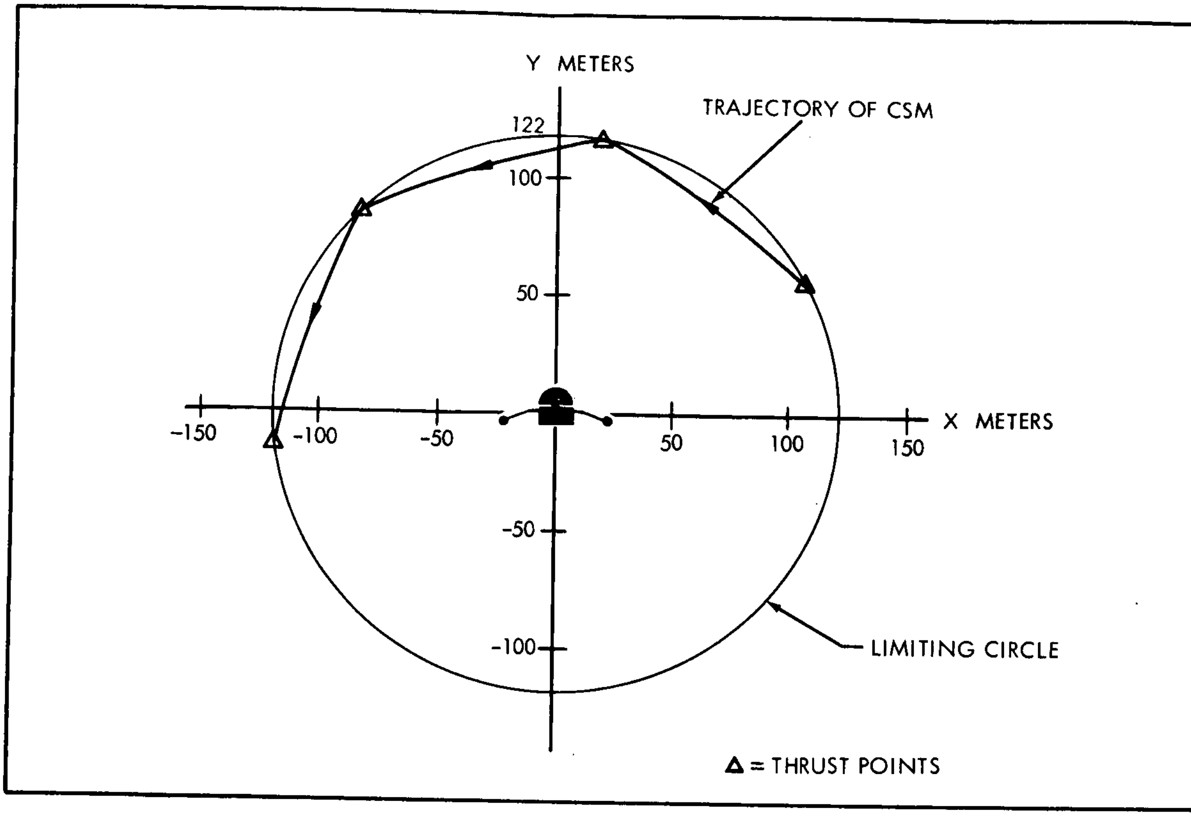

Fig. 3-26 Circumnavigation (In-Plane)

3.5 RECOMMENDED TECHNIQUE

The recommended rendezvous procedure, which is summarized below, begins with the establishment of a CSM parking orbit in the plane of OSO, continues with a coplanar orbit transfer and terminal closure, and concludes with the close-in maneuvers.

3.5.1 Orbit Transfer

The preferred mission would begin with a launch of the CSM into an orbit of 32.85 degrees. This will permit a reasonably large launch window (on the order of 175 minutes), and would eliminate a major plane change. Phasing time can be precalculated, and allowed for by not launching exactly coplanar, so that the difference in regression will make the vehicles coplanar at the desired time.

An additional launch velocity for a launch into a 32.85 degree at a latitude of 28.5 degree is needed to replace the velocity increment supplied by the rotation of the earth. This is calculated to be on the order of 131 mps (430 fps), and would be supplied by the Saturn IB launch vehicle.

A coplanar transfer to the OSO orbit can be initiated after a period of phasing to optimize the differential between the longitude of the ascending modes. The transfer angle must be on the order of between 100 degrees and 260 degrees (Fig. 3-27). This permits a ΔV less

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than 300 mps (980 fps) with a minimum of 115 mps (380 fps) centered at the 180 degree transfer angle. The time of transfer is flexible (i.e., 1600 seconds to 4160 seconds). Permitting OSO to be located within an angular range as wide as 160 degrees will allow a flexibility in initiating ascent. The transfer angle and the semimajor axis of the transfer ellipse are the critical factors in determining the ΔV requirement. The relative orientations of the perigee points of the actual orbits are not critical.

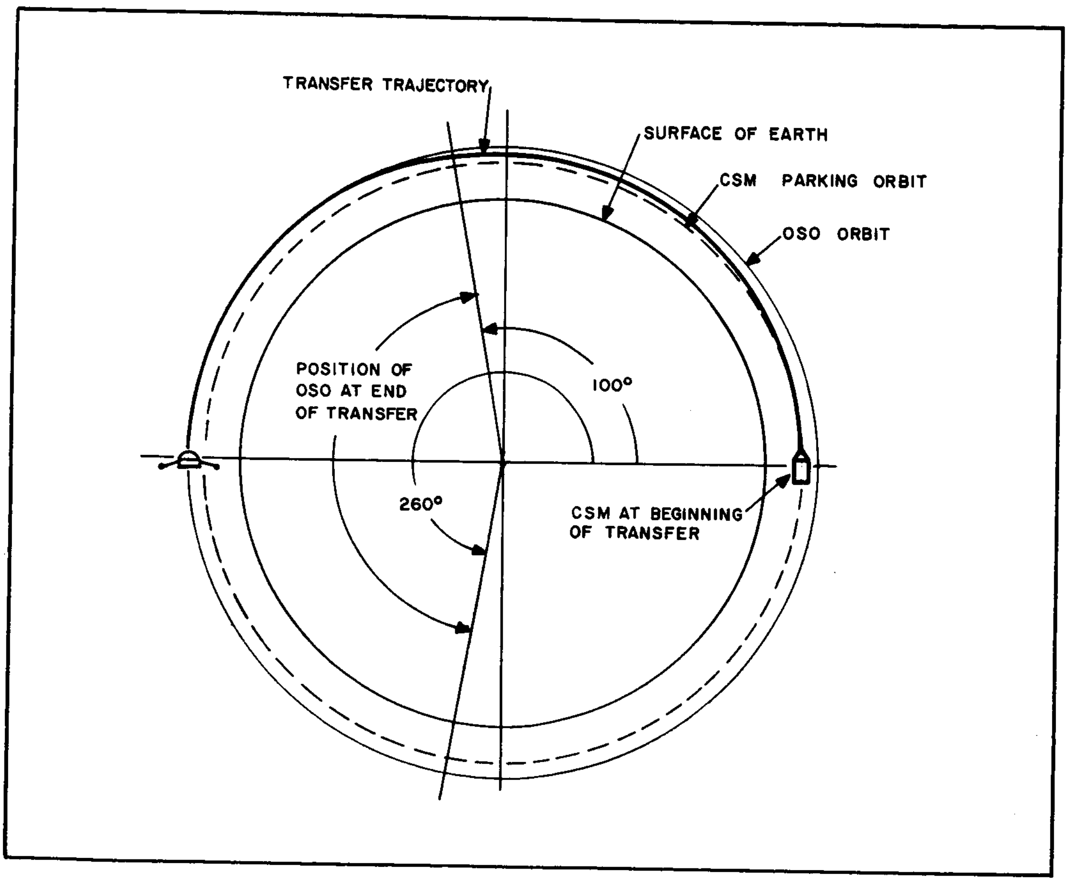

Fig. 3-27 Acceptable Transfer Region

3.5.2 Terminal Closure

The recommended terminal guidance procedure is to use a simple reticle sight to provide OSO-CSM angle data for an intercept course terminal maneuver. The ΔV for this phase would be 82 mps (270 fps). The maneuvers are performed as a function of time after transfer trajectory initiation; they require the astronauts to visually estimate range rate only at the end of the mission when the maximum closure rate is 10 mps (33 fps).

A time task outline of the basic terminal closure steps is presented below. The illustrated times are for a minimum energy transfer and therefore will vary with the actual transfer being programmed. These steps are as follows:

(1) 1500 seconds (after transfer initiation): Inertially orient the CSM and start a visual search for OSO. [Utilization of CSM Guidance and Navigation System (G & N) and RCS thrusters]

(2) 1950 seconds: OSO has been acquired and acquisition is being maintained.

(3) 2100 seconds: Orient CSM along LOS to OSO, track to compute LOS rate and approximate tangential velocity. (RCS thrusters)

(4) 2400 seconds: Orient CSM and thrust normal to LOS to null LOS rate, maintain LOS rate nulled. (RCS thrusters)

(5) 2700 to 2800 seconds: As OSO is approached, rotate CSM 180 degrees, (RCS thrusters). Apply SPS thrust to reduce closure rate. Reorient CSM along LOS and use RCS to manually null residual range rate.

3.5.3 Station Keeping Profile

The recommended mission profile is discussed below. The sequence and events considered are:

- Transfer to the initial station keeping position
- Perform first night time station keeping
- Transfer to initial circumnavigation position
- Perform day light circumnavigation
- Perform second night time station keeping
- Perform close-in capture maneuvers

See Table 3-5 for the sequence of events and time to complete each event and associated ΔV requirements. The nominal orbit day is 65.2 minutes and the average orbital night is 31.0 minutes.

The first event occurs during orbital day. Assume that the transfer to the initial station keeping position begins when the CSM is 152 meters (500 feet) below OSO and on the negative Y axis. The CSM then moves on a trajectory to a point 61 meters (200 feet) in front of OSO, where the night time station keeping begins. The time required to traverse the arc is regulated so that the CSM reaches the X-axis just as orbital night falls. This transfer time varies as indicated in Fig. 3-28. The ΔV requirements range from 3.32 mps (10.9 fps) for a 100 second transfer to 0.55 mps (1.80 fps) for 700 second transfer. Figure 3-29 portrays the ΔV as a function of transfer time. Figure 3-30 illustrates a transfer time of 500 seconds with a ΔV of mps (2.19 fps) in the mission profile.

Table 3-5

OSO CIRCUMNAVIGATION AND STATION KEEPING SEQUENCE OF EVENTS - TYPICAL CASE

Event	Day	Night	Time (sec)	ΔV (mps)	ΔV (fps)
1. Transfer to initial station keeping position	X		500	0.67	2.19
2. Station keeping		X	1860	0.36	1.18
3. Transfer to initial circumnavigation position	X		342	0.40	1.31
4. Circumnavigate	X		3570		
a) X-Y components				1.83	6.00
b) Z component				3.05	10.0
5. Station keeping		X	1860	0.36	1.18
6. Close in to capture OSO	X		250	0.91	2.98
TOTAL			8382	7.58	24.8

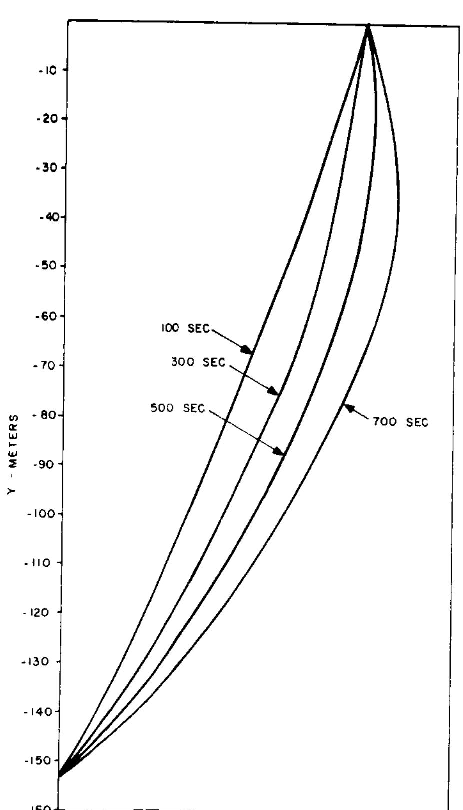

Fig. 3-28 Transfer to Night Station Keeping Trajectories

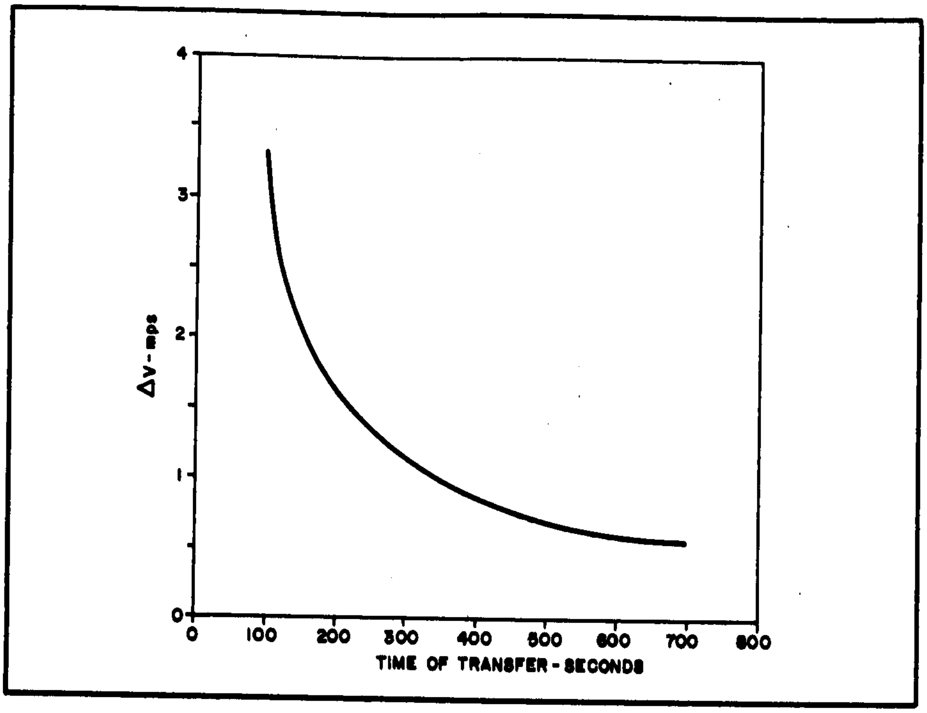

Fig. 3-29 Transfer to Night Station Keeping ΔV Requirements

The next event is a night time station keeping mode. The CSM thrusts to give itself 0.085 mps (0.28 fps) velocity away from OSO in a prescribed direction. This eliminates the danger of the CSM being swept into OSO during the orbital night. The CSM drifts for 1090 seconds until a range of 122 meters (400 feet) from OSO is reached and then thrusts to maintain its range within 122 meters (400 feet). The total ΔV required is 0.36 mps (1.18 fps). The night time station keeping lasts until the new orbit day dawns. This station keeping mode requiring two thrusts is presented in Fig. 3-30.

Following this is a transfer to a point where the circumnavigation can begin, as shown in Figs. 3-30 and 3-31. Time to transfer can be traded off against ΔV requirements. Here ΔV equals 0.40 mps (1.31 fps) for a 342 second transfer. It is desirable to provide as much time as possible for the circumnavigation, although transfer time must be short.

The circumnavigation (Fig. 3-31) will consume the rest of the orbital day, that is, 3570 seconds. In-plane components permit nearly three complete revolutions of the CSM about OSO. The out of plane motion is characterized by 10 excursions to one side of the orbital plane or the other. The total ΔV for the combined out of plane and in-plane motions is 3.05 mps (10.0 fps).

As the next orbital night falls, the CSM again thrusts away from OSO and begins the second night time station keeping mode. This phase of the mission will cost a ΔV of 0.36 mps (1.18 fps). Only one additional thrust will be necessary at a time of 1076 seconds to maintain range of less than 122 meters (400 feet). This is shown in Fig. 3-30.

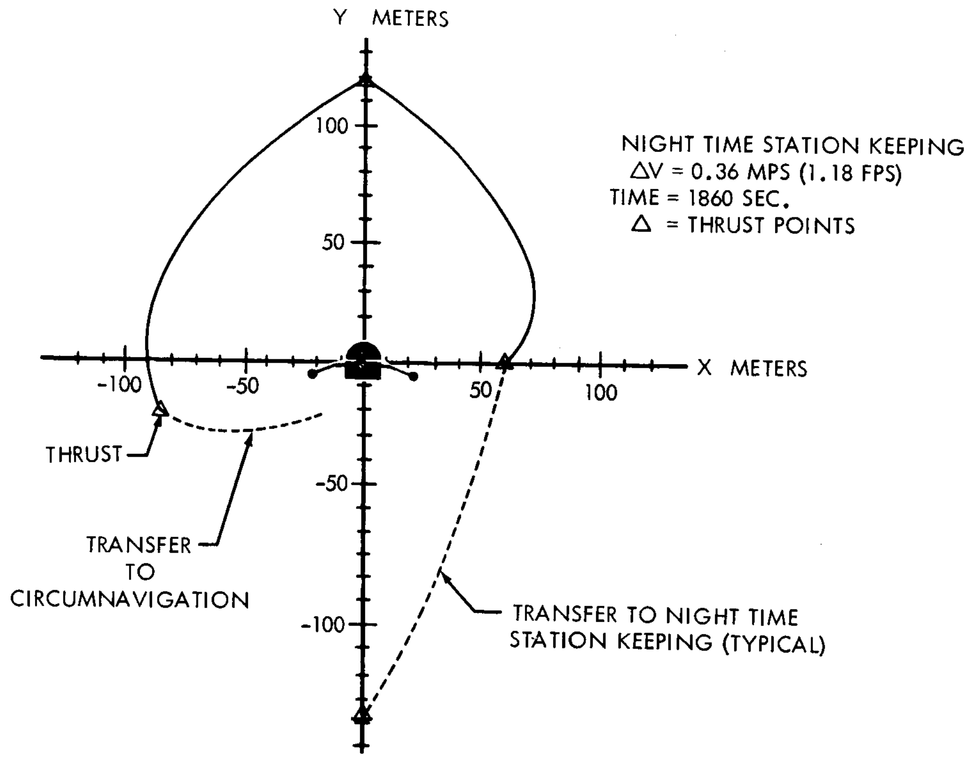

Fig. 3-30 Transfer/1st Night Time Station Keeping/Transfer

The final event is a transfer toward the OSO as a prelude to capture. Since OSO's axis of symmetry will not necessarily be in the X-Y plane, the motion must have a Z component in order to permit capture of the OSO. Again, the ΔV and time characteristics may be traded off. A ΔV on the order of 0.9 mps (3.0 fps) is a reasonable estimate. (Fig. 3-32.)

A total ΔV of 7.6 mps (24.8 fps) for the complete in-close maneuvers is small and is an amount capable of realization by the CSM (See Table 3-5).

The actual circumnavigation and transfers will be performed visually, as will the night time station keeping when the presence of the moon permits. The above analysis indicates representative ΔV requirements of the various portions of the mission. This will be similar to the actual ΔV requirements.

A summary of the CSM ΔV requirements for the entire rendezvous is presented in Table 3-6. It is pointed out that the ΔV requirements presented do not include the RCS fuel needed for the attitude orientation of the CSM. The ΔV total compares favorably with the 762 mps (2500 fps) given in the constraints for the allowable ΔV. However, if the allowable ΔV can be increased to a value on the order of 1000 mps (3280 fps), the margin of confidence for successfully completing an ESMRO mission is greatly enhanced.

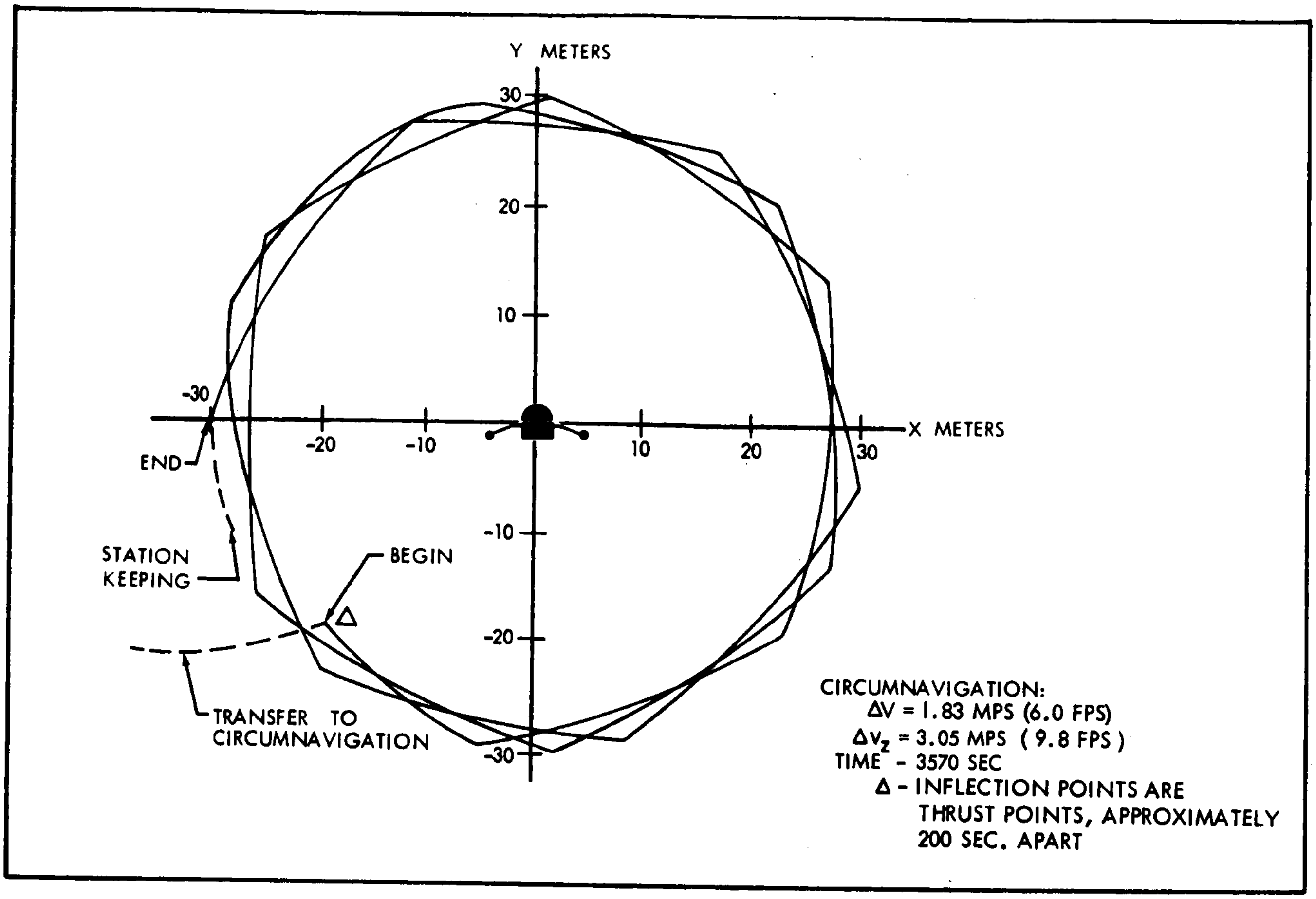

Fig. 3-31 Transfer/Circumnavigation/2nd Station Keeping

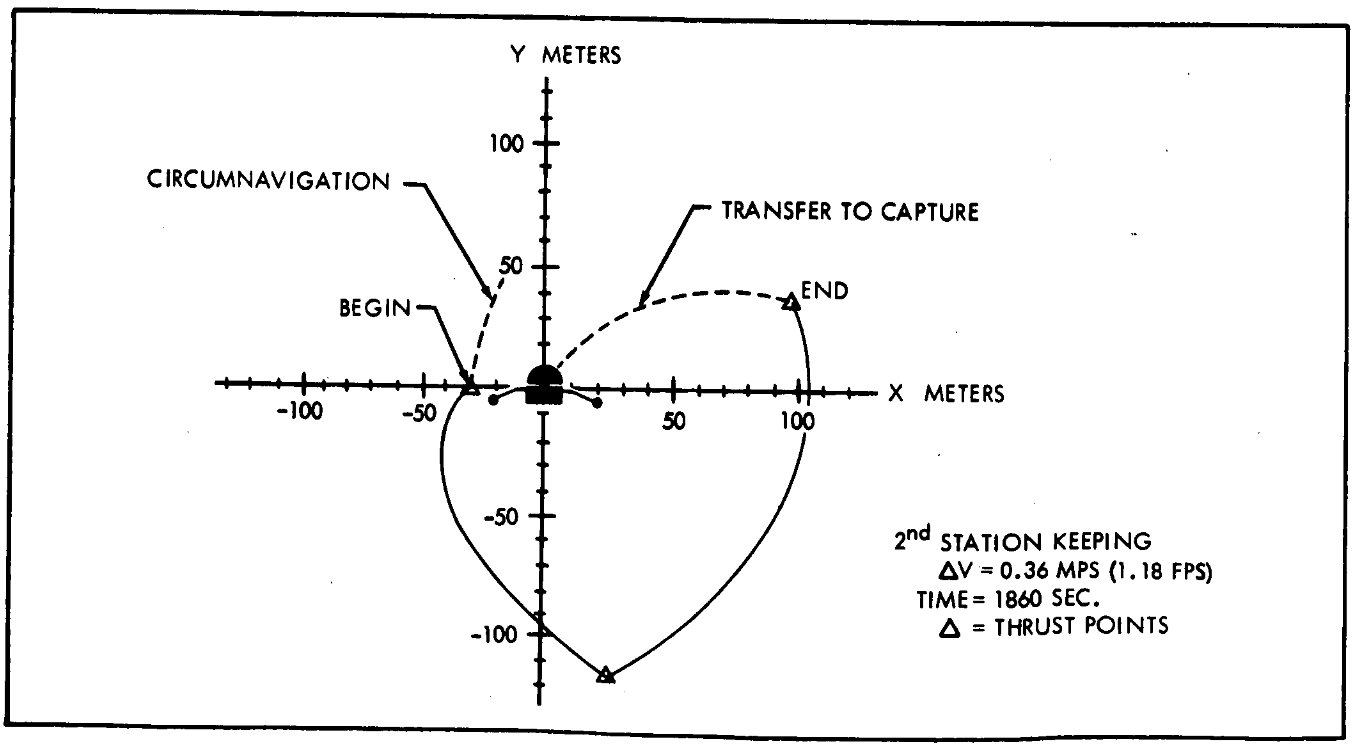

Fig. 3-32 Circumnavigation/2nd Station Keeping/Transfer

Table 3-6
ΔV REQUIREMENTS

Rendezvous Operation	ΔV (mps)	ΔV (fps)
Launch window	67	220
Orbit transfer	300	980
Terminal closure	24	80
Close-in maneuvers (precapture)	7.6	25
Close-in maneuvers (post-release)	7.6	25
TOTAL	406	1330

SECTION 4

CAPTURE AND RELEASE

Section 4
CAPTURE AND RELEASE

The technical studies discussed in this section cover the capture and release phases of the mission. Capture of the target OSO involves operations following the rendezvous and leading to the useful work phase. The capture of an orbiting OSO requires that it be contained under control of the CSM and that it be brought into kinetic equilibrium with the CSM. Various techniques and requirements for performing these operations have been analyzed. The release of the OSO after the useful work phase has been completed is virtually the reverse operation of capture, an analysis of its requirements and techniques is presented in this section. The recommended approach is presented after the detailed trade-off analysis and technical discussions.

4.1 GENERAL CONSIDERATIONS

The general considerations that have significantly affected the capture/release studies are presented in this section. These include criteria and constraints; functional requirements; and approaches considered.

4.1.1 Criteria and Constraints

The major criteria and constraints that have affected the capture and release studies are:

(1) The capture mechanism must be capable of capturing and containing a non-cooperative spinning OSO satellite.

(2) The capture operation must not endanger the CSM.

(3) The capture operation must be nondestructive to the OSO.

(4) The release operation must place the OSO in normal automatic operation.

(5) The capture mechanism must be jettisoned prior to the CSM de-orbit maneuver.

(6) The capture/release mechanisms must be compatible with the useful work operations.

(7) The capture mechanism must be capable of being stored in Section I of the Service Module or in the SLA. (It should be noted that Sector I of the Service Module may not be available for stowage of the capture mechanism; therefore this constraint has been changed to consider the spacecraft LEM adapter (SLA) volume for stowage of the capture mechanism.)

4.1.2 FUNCTIONAL REQUIREMENTS

The functional requirements for the capture phase are established by analysis of function 2.3 in Fig. 2-3. This function is detailed (Fig. 4-1) to indicate the main subfunctions and the flow logic of performing capture. The capture function consists of three main functional efforts: (1) Function 2.3.1 "Orient Position CSM with OSO"; (2) Function 2.3.2 "Make Ready Capture Device"; and (3) Function 2.3.3 "Control OSO". Each of these efforts has been functionally analyzed in more detail and is shown in Appendix E.

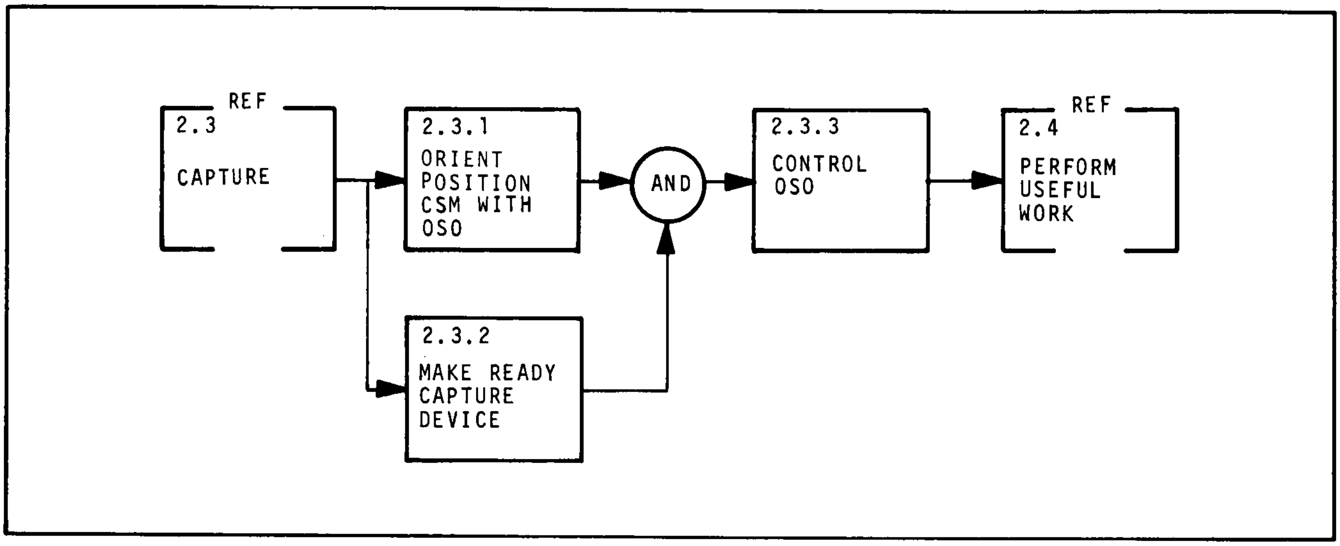

Fig. 4-1 Capture - FFD

The "Orient Position CSM with OSO" function requires that the CSM attitude be controlled while it is maneuvered with respect to the OSO. At the same time, the "Make Ready Capture Device" function requires that the capture mechanism be activated and checked out for the capture operation. The "Control OSO" function requires that physical contact be made with the target satellite and that it be stabilized with respect to the CSM.

Following the completion of the useful work phase, the target satellite is to be released as shown by Function 2.5 of Fig. 2-3. This function is detailed in Fig. 4-2, and it consists of five main functional efforts: (1) Function 2.5.1 "Orient OSO", (2) Function 2.5.2 "Activate OSO Operational Mode", (3) Function 2.5.3 "Perform Separation", (4) Function 2.5.4 "Stow or Jettison Capture Device", and (5) Function 2.5.5 "Inspect OSO". Each of these efforts has been functionally analyzed in more detail and is shown in Appendix E.

The "Orient OSO" function requires CSM maneuvering, so that the OSO pointing control can acquire the sun and OSO subsystems activate as required by the "Activate OSO" function. The "Perform Separation" function requires that the capture mechanism be separated from the OSO, and the jettison or stowage of the capture mechanism is required by the "Stow or Jettison Capture Mechanism" function. Post release inspection of the OSO is required by the "Inspect OSO" function to complete the orbital part of the ESMRO mission.

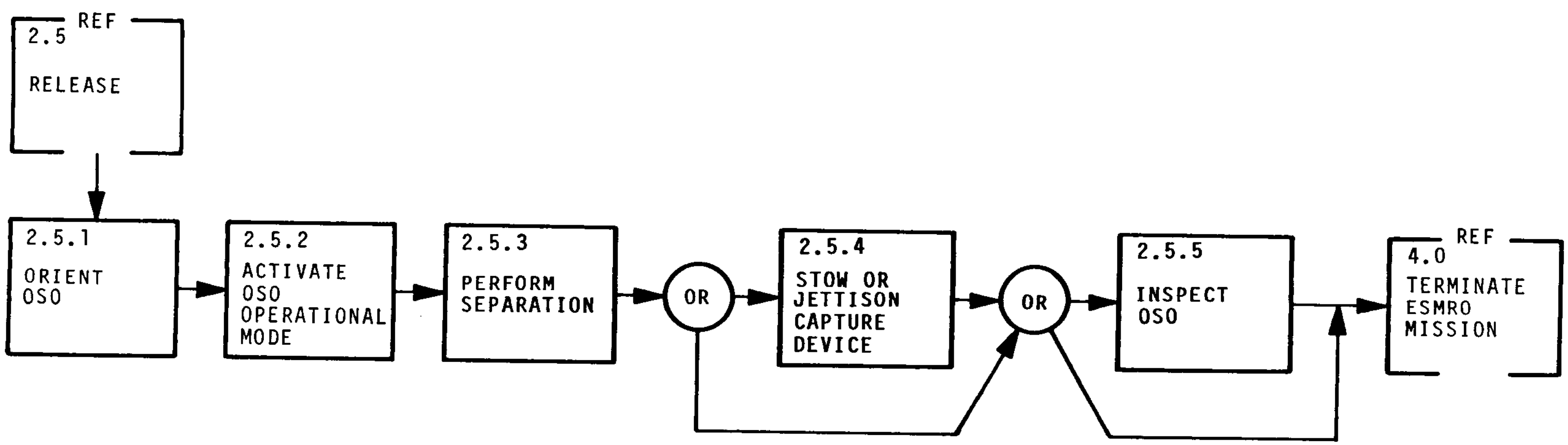

Fig. 4-2 Release - FFD

4.1.3 Approaches Considered

Evaluation of the functional requirements for the capture phase indicates that several major alternative approaches can be utilized. The following approaches have been examined and are discussed in Section 4.2:

- Method of coupling of capture device to CSM (i.e., free, tethered, semi-rigid, rigid)
- Location of capture device with respect to the CSM during the capture operation (i.e., remote, secured to Sector I, secured to CM docking adapter)
- Method of contacting and containing the OSO (i.e., nets, grapples, fly in funnel, encircling tape (Bolas), adhesive, yoke rigidized tether)
- Method of nulling the OSO rotation (i.e., despin by ground command versus application of braking torque by employing CSM RCS thrust)

Other associated problems that have been analyzed and are discussed in Section 4.2 are the following:

- Compatibility of the capture device with the useful work requirements
- OSO dynamics
- Capture dynamics
- Precapture inspection
- Release

4.2 TRADE-OFF ANALYSES AND TECHNICAL STUDIES

Various trade-off analyses and technical studies have been conducted to define the techniques and equipment required to perform the capture and release operations. (The results of each trade-off analysis as well as the associated technical studies are indicated in the following sections.) The logic established in conducting the first trade-off analysis was to determine the method for coupling the capture mechanism to the CSM. The second trade-off analysis considered the type of capture mechanism configurations. A third trade-off analysis considered the possible capture mechanism locations on the CSM. All of these trade-off analyses were influenced by a secondary trade-off consideration of performing the EVA useful work as discussed in Section 5.

4.2.2 Capture Mechanism Configurations

The capture mechanism is to make physical contact with OSO, attach to it, null all rotations, and maintain the OSO in position and rate equilibrium with the CSM. The spinning of the OSO presents the major problem in capturing it, since the spin angular momentum must be contended with. The recommended method for despinning the OSO is to provide despin capability in the capture mechanism and to take advantage of the gyroscopic properties of the spinning OSO. Such a despin mechanism can also provide a more general capture mechanism that can be used on inactive OSO's, as well as active OSO's and other types of satellites. A number of configurations of attachment mechanisms have been evolved and investigated to accomplish these tasks. Design concepts are presented for nine configurations which appear most suitable for performing these tasks. A brief description of each of these mechanisms and a detailed evaluation presenting the advantages and disadvantages of each is presented in the following sections.

4.2.2.1 Enveloping Net

A net deployed from the CSM would completely envelope the target OSO. A typical net capture system illustrated in Fig. 4-3 consists of a net attached to an inflatable ring on the end of a deployable tube. The net is connected to the ring by a series of spring clips and to the CSM by a flexible line. As the target OSO contacts the net, it disengages the spring clips. The net envelops the OSO, and the line attached to the net is reeled out. The relative linear and angular momentum of the OSO would be dissipated by feeding out the line at a controlled tension until kinetic equilibrium is achieved and then maneuvering the CSM for position equilibrium. This attachment system can be used to capture various satellites and configurations, over a wide range of approach velocities and angles. However, a possible hazard to the CSM exists since attainment of position and kinetic equilibrium between the CSM and the target satellite would require very accurate control of the tension in the connecting line as well as precision maneuvering of the CSM which would be quite difficult. In addition, the net can damage satellite appendages because it envelops the satellite, so the accessibility for performing useful work is unfavorable.

4.2.2.2 Net Over OSO Sphere

A net could also be wrapped around one of the OSO external gas spheres rather than around the complete satellite. The configuration and operation would be similar to the enveloping net, but the system size would be decreased at the expense of an increased precision to orient the net. This specific technique would be applicable only to the OSO or other similar satellites. Further control of the captured OSO would be very difficult.

4.2.2.3 Grapple, OSO Spheres/Arms

A grappling device would be deployed either on a boom or by a small rocket to hook around an arm and/or pressurized sphere of the target OSO. Position and kinetic equilibrium

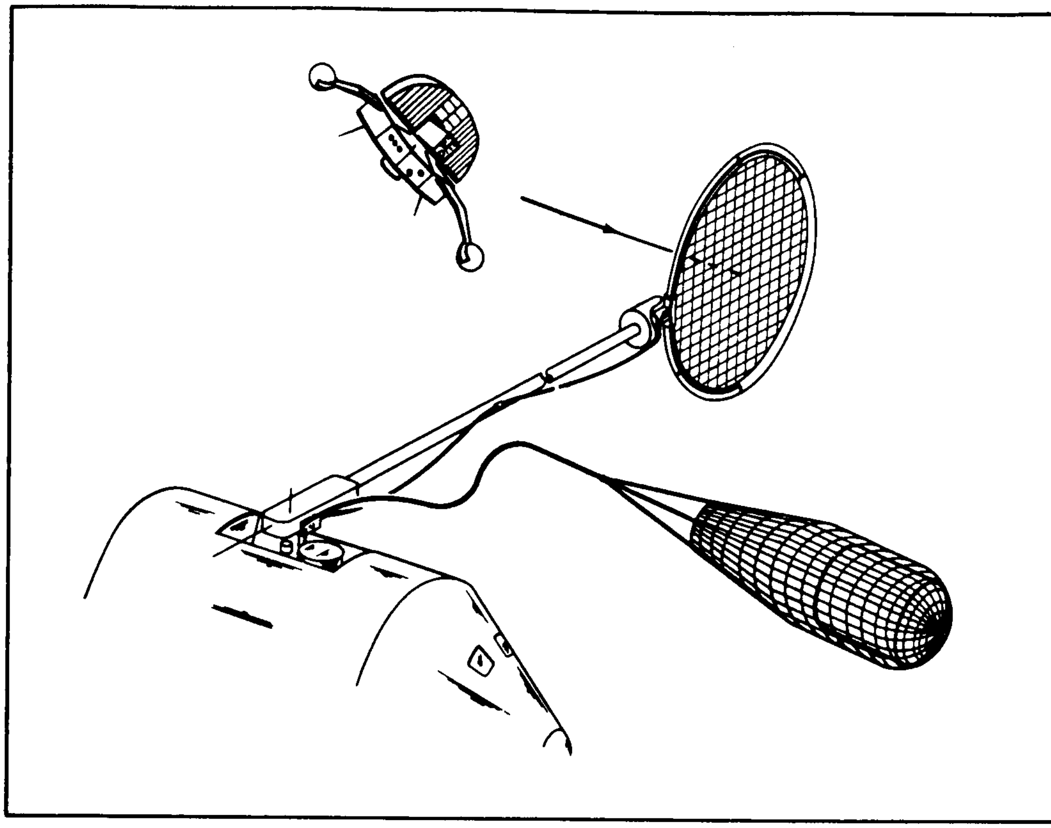

Fig. 4-3 Typical Net Capture System

would be achieved in the same manner as the net capture concepts. The capture system would be the lightest of any of the concepts being considered. The basic principle could also be used on other satellites, but would be very limited, since damage to satellite appendages and surfaces would probably occur from the grapple operation.

4.2.2.4 Remote Manipulators

The concept of remote manipulators consists of a servo-controlled manipulator that would be deployed from the CSM and would latch onto the bottom flange of the OSO. The latching or clamping would be performed by mechanical fingers on the end of an articulated tube. These fingers would be rotated to the same velocity as that of the spinning OSO, and the manipulator positioned along the OSO spin axis for attachment. Rotation of the OSO would be gradually nulled by the system.

The remote manipulator provides a positive and controllable attachment that is reusable. If an inadequate attachment with the OSO is made on the first attempt, the OSO can be released and the attachment procedure repeated. However, if an inadequate attachment is made and not released, the resultant effect would be a violently uncontrolled OSO. Also, spinning up the manipulators before OSO contact complicates the design, since controls and power for the latching mechanism must be transmitted through a spinning joint. Remote manipulators are complex and expensive; at this time, none have been built and qualified for space. However, they have been built and used in the extreme environment encountered by deep submergence oceanographic vessels and also in laboratory work. Another possible disadvantage of manipulators could be a lead time of 48 to 60 months to obtain space qualified equipment (Ref. 8).

4.2.2.5 Fly-In Funnel

This capture system consists of an elastic conical funnel or tubular net funnel that would be attached to the CSM and maneuvered so that the OSO would pass within the diameter of the funnel. A typical tubular net funnel would consist of six telescoping tubes with elastic cables connected between alternate tubes and diametrically opposite tubes. As the OSO contacts the funnel, the force is maintained at an acceptable level by energy absorbers in the cables and telescoping tubes. The elastic funnel would consist of an elastic sheet material supported from a fixed structure.

The funnel can be stowed in a small volume and deployed for use. It can be used for capture of satellites other than OSO and does not require precision CSM maneuvering. However, this capture technique does not positively attach to the OSO, and its relative spin angular motion must be damped by friction or entanglement with the cables or the elastic sheets. Antennas or other proturbances from the OSO would probably be damaged during capture.

4.2.2.6 Encircling Tape (Bolas)

The encircling tape attachment device would perform similar to a bola; that is, it would encircle the OSO with adhesive tapes which attach to the OSO as well as to each other. The mechanism consists of three or four pressure sensitive adhesive tapes which are stored on spools and have a solid propellant rocket slug on the end of each tape (Fig. 4-4). The attachment device is stowed at the end of a boom. The boom is maneuvered toward the target and the solid propellant slugs ignited. The slugs are propelled in parabolic trajectories withdrawing the adhesive tape from the spool. As the tape contacts the OSO, the momentum of the slug causes it to encircle the OSO. Adhesive on the tape attaches to the OSO, and the encircling tapes are bonded to each other. The spools are then rewound to draw the tape tightly around the OSO and up to the boom.

4.2.2.7 Rigidized Tether

Active OSO's can be commanded to despin from the ground, or the CSM, by a command system that activates the satellite spin gas control system. After the satellite has been despun, a rigidized tether would be used to attach the CSM to the OSO by EVA. This capture concept incorporates a sprial wound metal hose connected to the CSM. A clamp on the end of the hose would be attached to the OSO last stage attachment flange. After attachment, cables installed inside this metal hose would be used to apply an axial load to the hose.

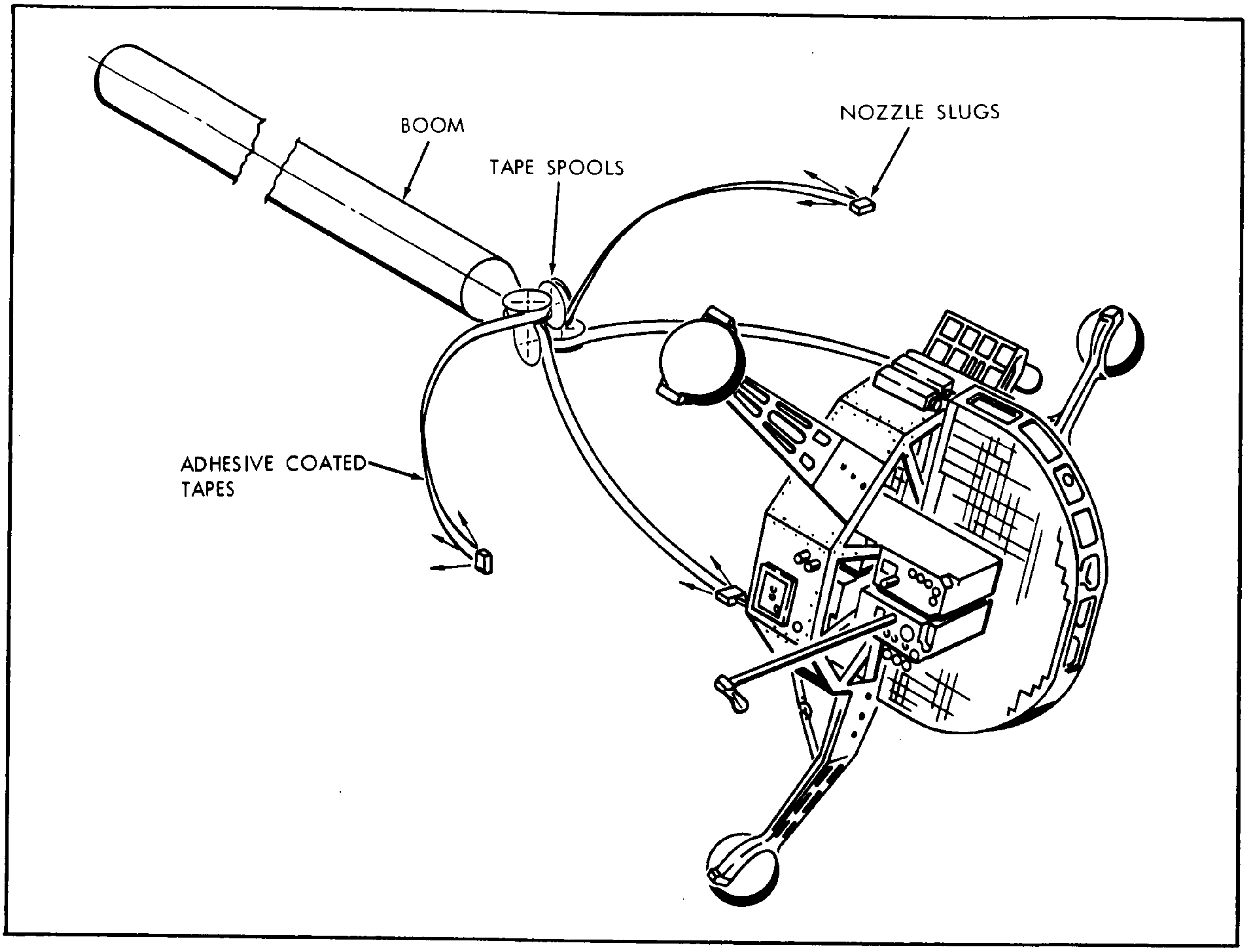

Fig. 4-4 Encircling Tape on Boom (Bolas)

Under compression, the spiral wound elements of the hose interlock and form a rigid tube. This technique could not be used, however, on inactive target OSO's that could not respond to the commands or that had no spin control gas. In addition, a command despin capture technique would have a limited application in the capture of other satellites.

4.2.2.8 Yoke Mechanism

The yoke capture mechanism would be mounted on the end of a boom attached to the forward end of the CSM. The configuration would require a docking operation to attach it to the front end of the CSM. The yoke capture mechanism latches onto the three arms of the OSO to capture and control it (Fig. 4-5). Three fingers on the ends of the boom are rotated at the spin velocity of OSO and deployed along the satellite spin axis from the underside of the wheel. The fingers contact the arms and latch about them. Since the OSO arms are spaced at 120 degree intervals, precision positioning of the fingers is not required. The dynamics of contact tend to center the OSO in this mechanism.

This system is a very simple mechanical design and would provide a positive attachment to the OSO. However, it is suitable for use only on OSO type satellites and would not be adaptable to other satellites. The mechanism, except for the attaching head is identical to the adhesive concept (which is to be discussed next) and therefore, the yoke head and the adhesive head could be interchangeable components on the same basic capture mechanism.

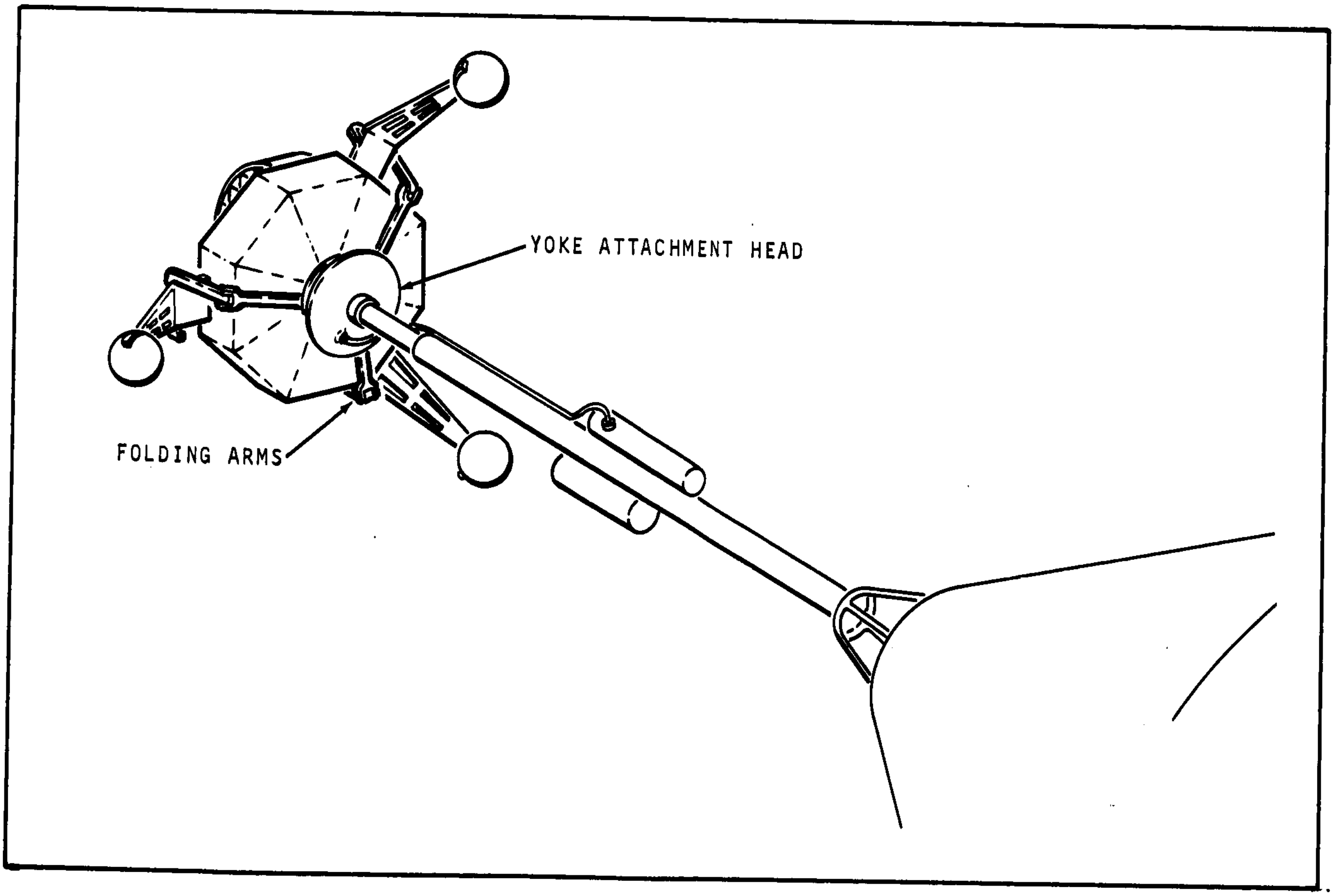

Fig. 4-5 Yoke Capture Mechanism

4.2.2.9 Adhesive Head

An adhesive head on the end of a boom attached to the CSM similar to the yoke head configuration would be maneuvered into contact with the bottom of the OSO and adhere to the wheel surface as shown in Fig. 4-6. The adhesive head would consist of a ring of pressure sensitive adhesive that can be despun to nullify the OSO spin agular momentum; or spun-up to spin the head prior to capture and to respin the OSO prior to release. This ring would fit around the OSO attachment flange which mates with its launch booster. A flexible joint in the capture mechanism would permit angular misalignment between the CSM axis and the OSO spin axis to be compensated for, as the relative small translation forces increase as the adhesive ring is making full contact with the OSO wheel. A spring in the boom with a ratchet locking mechanism would compress and lock at its extreme position to absorb the translation energy of the impact, which is expected to be made at less than 2 feet per second. After impact and locking of the compression spring, the adhesive will have set, and the adhesive head and OSO can be despun. A centering mechanism would engage the OSO adapter flange by manual operation during EVA, to center the OSO on the boom. The adhesive is released from the OSO while centering; this is accomplished by heating it beyond its yield temperature with internal wiring.

Adhesives have been successfully used in space applications, and considerable experimentation has been conducted in their application under high vacuum (Ref. 9). This effort has indicated that commercially available adhesives could be applied under high vacuum that would provide tensile strengths of 10 psi less than one minute after application. The performance of a typical adhesive as a function of vacuum condition and temperature testing during the Emerson Electric study program is shown in Figure 4-7. Higher strength adhesives are also available, but they are difficult to apply in a vacuum and/or require considerably longer curing times.

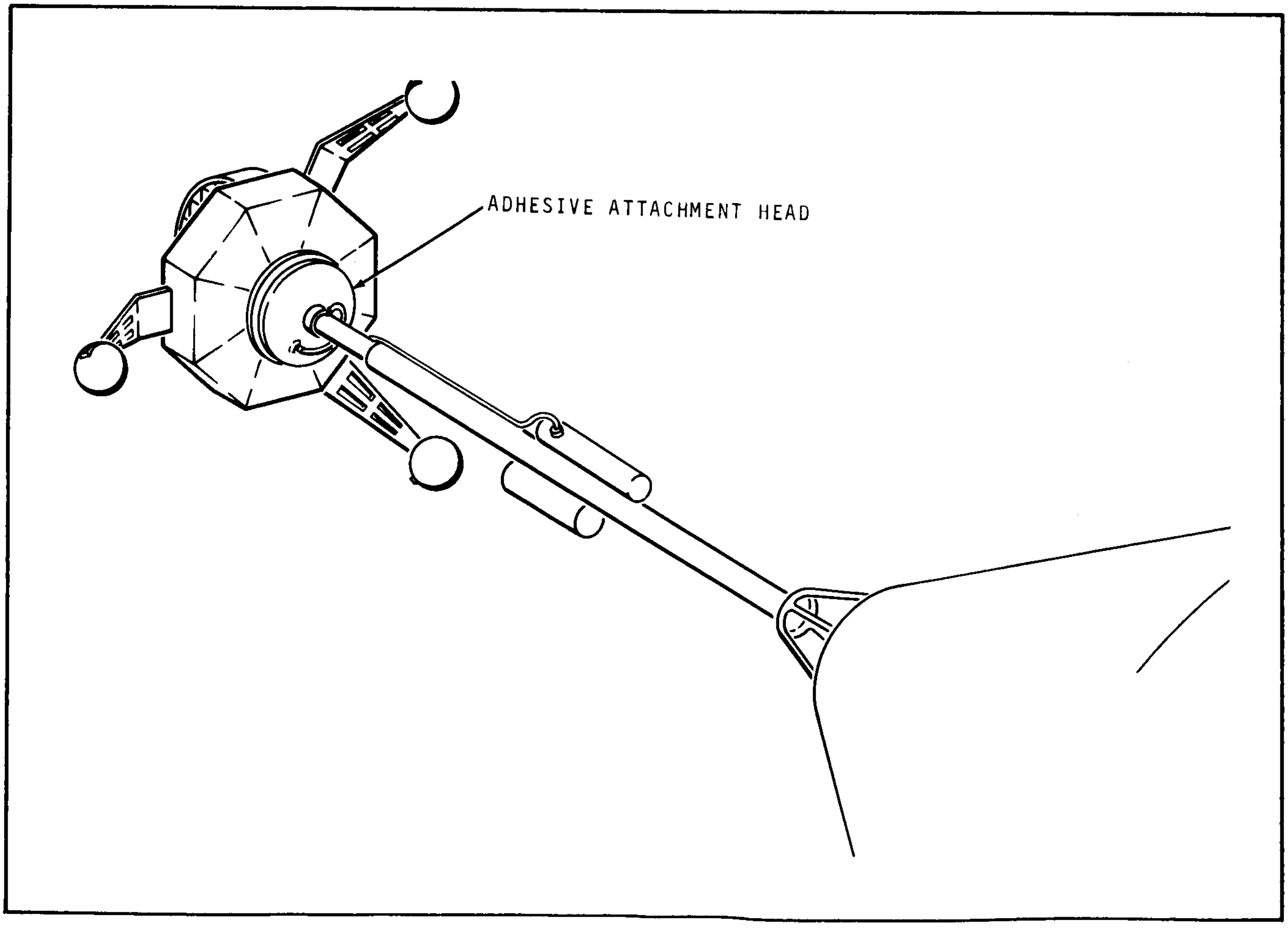

Fig. 4-6 Adhesive Capture Mechanism

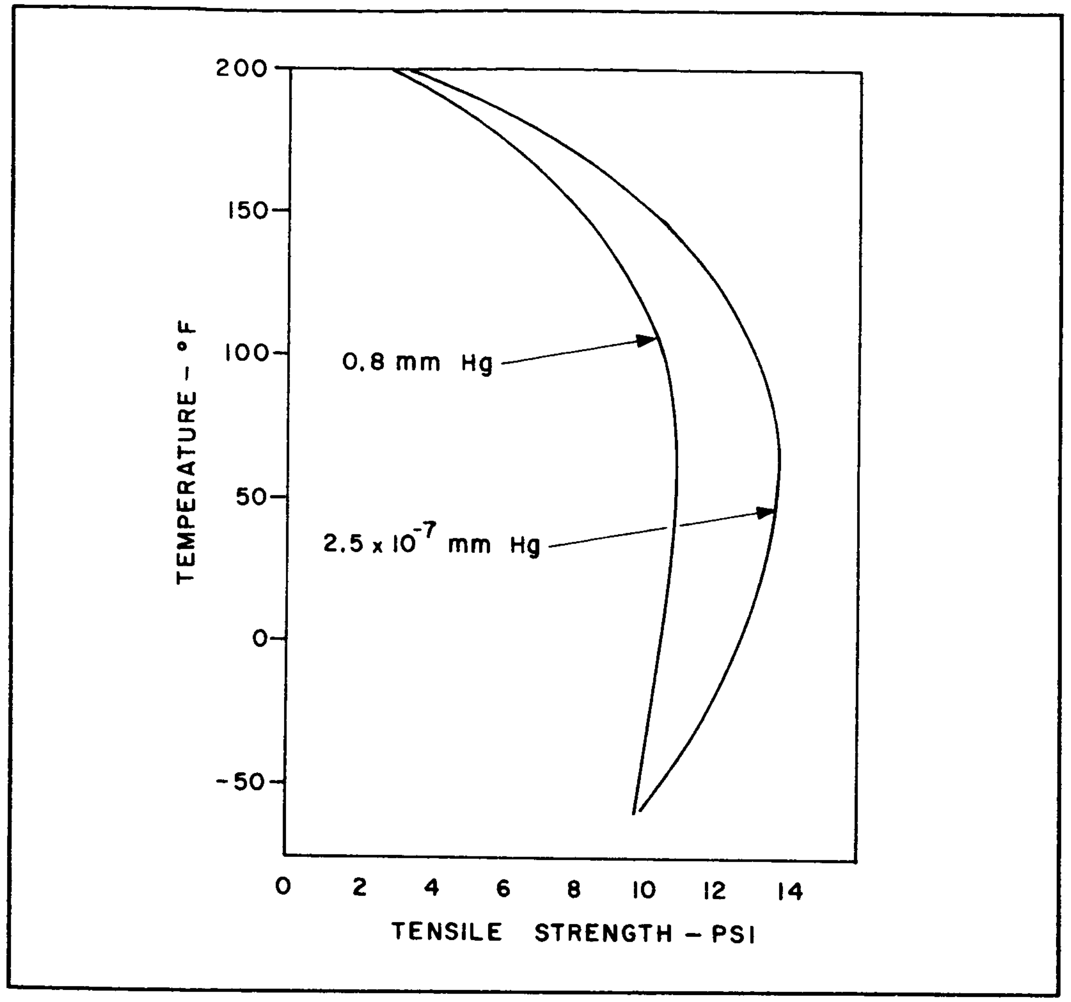

Fig. 4-7 Adhesive Performance

4.2.2.10 Capture Mechanism Evaluation

A weighted evaluation of these capture mechanisms has determined those concepts suitable for more detailed analyses. Evaluation criteria have been weighted by grading each item a maximum of three, five, or seven points (Table 4-2). The main emphasis is on CSM and crew safety; this is allocated a maximum of seven points. Mechanical and operational complexity, despin and release capability, possible damage to OSO, accessiblity of OSO to work, and ease in which techniques can be ground tested and simulated are all equally weighted at five points. Although respin of OSO is important, this feature in a capture head is rated low, since respin could also be achieved by adding a reaction device to the OSO. Storage volume and weight are also weighted low, since none of the concepts considered are excessively heavy or require excessive storage volume. The remaining factor of the low weighting, application to other satellites is important, but it has not been considered a mandatory feature since the capture of an OSO satellite is the primary objective of this study.

Table 4-2

CAPTURE HEAD TRADE-OFF EVAULATION

Weighting	0-7	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-5	0-3	0-3	0-3	0-3	
Capture Head Concept / Evaluation Criteria	CSM and Crew Safety	Mechanism Complexity	Operational Complexity (Attachment & Equilibrium)	Probable No Damage to OSO	Controllable Despin	Development Cost	Accessibility for Work on OSO	Difficulty Releasing	Can Be Simulated in 1 g	Suitable for Respin	Stowage Volume	Applicable to Other Missions	Weight	Total
Enveloping Net	3	5	0	2	0	5	0	0	0	0	3	2	3	23
Net over OSO spheres	2	5	0	3	0	5	3	3	2	0	3	0	3	29
Grapple OSO spheres and Arms	2	5	0	3	0	5	3	3	2	0	3	0	3	25
Remote Manipulator	6	0	2	5	5	0	5	5	5	3	2	3	1	42
Fly-in funnel	5	3	5	2	5	3	1	1	5	2	0	1	0	33
Encircling tape (Bolas)	4	2	2	2	2	4	1	0	0	0	2	2	2	23
Adhesive	6	3	3	5	5	5	5	4	5	2	2	3	2	50
Yoke	6	4	4	4	5	5	4	5	5	3	2	0	2	50
Rigidized tether (command despin)	5	4	3	5	0	5	5	5	5	0	3	0	3	43

The rigidized tether with command despin is rated high; however, because it requires a command despin which is not compatible with the study program constraint of capturing a noncooperative satellite, it requires EVA to effect capture; since this is a limited application, it has not been further considered.

The remote manipulator is rated very high in performance, but its complexity and high cost bring its overall rating down. However, for advanced missions in the post 1972 period, remote manipulators should be of considerable importance.

Because of either possible damage to the OSO, contamination of the OSO satellite, or difficulty in ground simulation testing, the enveloping net, the net over OSO spheres, the grapple OSO spheres and arms, the fly-in funnel and the encircling tape (Bolas) all have relatively low ratings, and thus have been discarded as possible capture mechanism concepts.

The adhesive and the yoke capture mechanisms are rated highest of the concepts considered, as indicated in Table 4-2. The chief disadvantage of adhesive, not apparent in this evaluation, is that the ability to apply an adhesive in space in an application such as this capture concept is not proven, although adhesives have been used in space for other purposes and applied in simulated space environments during testing. The yoke is a straight forward mechanical device suitable only for OSO type satellites, and would not be applicable to other type satellites. It is a comparatively simple design and should be very suitable for use with OSO. The adhesive head and yoke head capture mechanisms would use the same boom and flexible joint and despin mechanism for controlled degrees of freedom. Only the actual attachment head itself is different. Both concepts represent a feasible configuration for capturing a noncooperative spinning OSO satellite. In order to present a singular capture mechanism concept, the adhesive attachment head is depicted and treated throughout this report.

4.2.3 Capture Mechanism Location on CSM

The capture mechanism must be attached to the CSM so that it requires a minimum of interfacing and does not interfere with CSM operational performance. Crew visibility of the capture mechanism during the capture operation is of primary concern. Selection of location depends on the technique by which the CSM effects capture and where the capture mechanism is stowed in the vehicle.

Should a net be used to capture OSO, a fly-by approach would be required and the capture mechanism deployed orthogonally to the longitudinal axis of the CSM. However, the most suitable capture mechanisms - adhesives, yokes, and manipulators - all require attachment to the OSO at the bottom of the wheel along the spin axis. The capture mechanism should therefore be positioned along the CSM longitudinal axis so the capture maneuver is very similar to docking. This maneuver is one which the CSM is designed to perform, and the astronauts will be thoroughly trained to perform. Furthermore, this location affords excellent crew visisility during the capture operation.

For spacecraft and launch vehicle systems being considered, two storage areas might be used for the capture device. Sector I of the Service Module (SM), or the spacecraft LEM adapter (SLA). The space available in Sector I is not currently well defined, and it is anticipated that some of the total volume will be used for additional Apollo expendables. The large volume available in the SLA indicates there should be no shortage of storage space for the missions under consideration..

Two locations are suitable for attachment to the CSM with a minimum of interfacing; these are Sector I of the SM, or the CSM/LEM docking adapter. Therefore, there are four stowage/attachment combinations that can be considered for the capture mechanism:

- Sector I stowage - CSM/LEM docking adapter attachment
- SLA stowage - Sector I attachment
- Sector I stowage and attachment
- SLA stowage - CSM/LEM docking adapter attachment

Sector I stowage and CSM/LEM docking adapter attachment or SLA stowage and Sector I attachment both require EVA to unstow and attach the mechanism to the CSM. Since considerable EVA would be required on the useful work phases of this mission, it is desirable to minimize EVA and the associated necessary CSM depressurizations. In addition, the maneuvering and attachment of the capture mechanism would be a difficult task to perform by two astronauts in EVA. Therefore, these stowage/attachment concepts were not considered suitable for the ESMRO mission.

The remaining stowage/attachment combinations do not require EVA to unstow, set up, and deploy the capture mechanism. The Sector I stowage and attachment would deploy the mechanism and position the attachment device in front of the CSM. This would require a relatively long articulated boom which would have to endure the loads of contact and equilibrium stabilization. However, when attached to Sector I, power and control could be provided through the connections from the CSM. The capture mechanism could also be stowed in the SLA and attached to the CSM in a docking maneuver similar to the CSM docking with the LEM. A short and simple boom would be positioned directly on the longitudinal axis of the CSM. Power and data links would have to be self-contained on the capture mechanism device and controlled by an RF link, or else provided through an umbilical connector to the CSM. However, self-contained power and control is advantageous since the equipment would be self contained and not dependent on CSM systems.

Weight, minimum complexity, reliability, and operational simplicity all favor the use of the simple boom stowed in the SLA and attached to the CSM in a normal docking procedure. The system has greater evolutionary capability since it could be used on the LEM with a suitable docking adapter or on any future spacecraft which has a similar docking adapter.

4.2.4 OSO Dynamics

The OSO satellite can be dynamically approximated by four interconnected bodies consisting of the wheel and an upper structure containing the sail, pointed experiment package, and the nutation damper. The mass and inertia of these bodies is summarized for a representative OSO in Table 4-3. (Additional detail information on OSO dynamics can be found in Appendix A.) These values are typical of all OSO satellites. The wheel and upper structure are interconnected by an aluminum shaft on bearings. A torque motor on the shaft drives the upper structure relative to the wheel. The pointed experiments are mounted in the sail section and a torque motor drives them over a ±3.5 degree range in elevation.

Table 4-3
OSO II MASS AND INERTIA DATA

OSO Component	Mass (Slugs)	Inertia (Slug-ft^2) Ix	It	Iy	Is	Iz
Wheel	12.15		17.2		30.4	
Sail	2.59	1.2		1.8		1.1
Pointed experiments	3.07	2.5		0.3		2.5
Nutation damper bob	0.26					

The OSO satellite uses two dynamic modes of operation, one during the day portion of each orbit, and the other during the night. During orbital day, the wheel spins, and a torque motor drives the sail section at a rate equal but opposite to that of the wheel. Therefore, the sail section of the OSO remains fixed in space oriented towards the sun while the wheel spins. The spin control system maintains the wheel rotation between 30 and 39.6 rpm. The spin control system is turned off during orbital night, and bearing friction causes the sail section to start rotating with the wheel section. The wheel shows down, and the satellite stabilizes at a rotation of between 26.4 and 33.6 rpm. At the slower rate, maximum unbalances of the pointed experiments cause a wobble of 10 minutes of arc about the OSO spin axis (Z). The spin rate of an inactive OSO decays about 2 percent per month from its initial value. This decay is illustrated in Fig. 4-8. for initial spins of both 26.4 and 33.6 rpm. Even after 4 years of inactivity, the OSO spin rate would be greater than 10 rpm; thus, the OSO would still act as a relatively rigid gyro.

4.2.4.1 OSO Dynamic Situation

Three possible OSO dynamic situations could be encountered at capture. These are:

- Wheel spinning, sail structure not rotating
- Wheel and sail structure spinning, bearing free
- Wheel and sail structure spinning, bearing locked

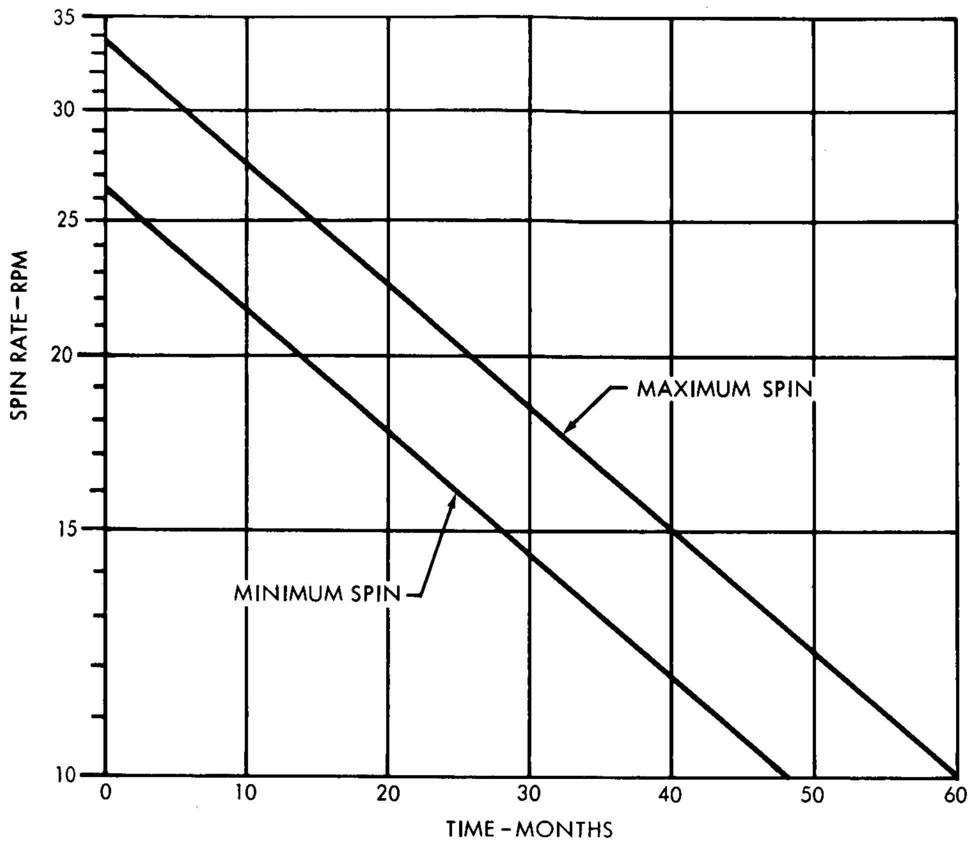

Fig. 4-8 OSO Spin-Decay - Control System Inoperative

The first situation represents the normal orbital day OSO operational mode, and therefore the spin control system must be in operation. This implies an active OSO which has not been turned off by command. The second situation, wheel and sail structure spinning with the bearing free, is characteristic of normal orbital night operation. This situation could also be encountered on an inactive OSO, or an active OSO in which the spin control system has been commanded off. The wheel and sail structure spinning, with the bearing on the connecting shaft locked, is the third dynamic situation that could be encountered. Although this situation might occur on an OSO in orbit a long time, OSO flight data to date has not indicated any bearing degradation that eventually might cause locking. The free and locked bearing situations represent extreme conditions. Actual degradation might result in bearing friction at any level between these extremes.

4.2.4.2 Despin Torque-Time Relationships

The procedures and equipment required for despin of the OSO is the same for all the dynamic situations; only the sequence and time of the actual despin vary. If torque is applied to an OSO in which the bearing connecting the wheel and sail structure is free, the wheel despins first. Viscous and coulomb (or dry friction) bearing friction then nulls the rotation of the sail structure. If the connecting bearing is locked, both the wheel and upper structure are despun simultaneously.

For either situation, the OSO can be despun in a short time with a low torque level. A continuously applied torque of one lb-ft despins the wheel from 30 rpm in 97 seconds. Bearing friction would then null the rotation of the sail structure in about one minute. If the bearing is locked, one lb-ft of torque despins the complete OSO in 107 seconds.

4.2.4.3 Despin/Spin-up Techniques

OSO despin can be implemented by applying a torque to the attachment head which is spinning with the OSO relative to the capture boom. Three basic concepts which could be used are as follows:

- A reaction system in the attachment head
- A torque motor/gimbal
- Mechanical friction

The reaction system could be used to null the rotation almost to zero, and friction would be allowed to complete the despin of OSO. The torque motor could provide complete despin and also precisely orient the OSO. Both the torque motor and the reaction system can also be used to respin the OSO prior to release. Friction between the attachment head and capture mechanism support would despin the OSO without any additional mechanism, but this could not respin the OSO. Time for despin depends on the bearing friction applied; five to ten minutes is a realistic time. The time to despin mechanically can be decreased by adding a braking system to the capture mechanism.

Each of these concepts would be simple and have low weight. Furthermore, they are not mutually exlusive in an evolutionary capture mechanism development. For example, a capture mechanism using friction for despin and having no respin capability would be acceptable for a mission in which respin was not required. A controlled despin and respin capability could then be added to the capture mechanism for the next mission in which respin would be required.

Spin-up could also be accomplished by putting a spin propulsion package on the OSO which would be activated at release. This would obviate the need for centering the OSO on the attachment head drive, but this would be less reliable. The package would be installed during the useful work EVA phase of the mission. The OSO dynamic balance must be maintained after the addition of such a package.

A realistic trade-off analysis of the despin/spin-up mechanism cannot be made without a more detailed design of the capture mechanism. However, all of the concepts discussed are suitable for use with the preferred capture mechanism, and it is recommended that a spin-up and despin mechanism be part of the capture mechanism.

4.2.5 Capture Dynamics

The OSO capture operation includes approach of the CSM along the OSO spin axis and contact and attachment of the capture mechanism to OSO. If the forces of contact and attachment are aligned with the OSO centroid, only a translational acceleration is applied to the OSO. However, eccentric contact of the capture mechanism applies a moment to the satellite and induces rotational motions. The anticipated eccentricity at contact should be small, as the Gemini program has shown that it is possible to precisely maneuver a spacecraft up to a stabilized satellite.

4.2.5.1 Translation

The capture mechansim is conceived to include a compression spring in series with the attachment assembly. The capture procedure consists of the CSM closing on the OSO at a velocity vector coincident with their center lines. The capture mechanism contacts the OSO, compressing the spring. At the time that the CSM and OSO attain the same linear velocities, the spring is locked, thereby transferring kinetic energy of the system to potential energy of the spring and effectively reducing the energy of the system. The two vehicles then oscillate about their center of mass at a frequency determined by the spring constant of the structure. Translation forces at the attachment mechanism/OSO interface have a maximum value equal to the force required to compress the spring, which is present when the spring is locked.

A digital computer analysis was conducted to determine coliner capture dynamics for various closing velocities and comression spring constants. The mathematical model for this analysis is presented in Appendix C.

The analysis was conducted for closing velocities from 0.5 ft/sec to 5 ft/sec, and for spring constant values of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 lb/ft. Other constants used in the analyses include:

- Mass of CSM = 870 slugs
- Mass of OSO = 18.5 slugs
- Distance between centers of mass at contact = 25 feet
- Spring constant of the structure = 4.56×10^6 lb/ft

Figure 4-9 indicates the time after impact at which the capture mechanism spring would be locked as a function of the spring constant. This time is independent of initial closing velocity; and this is the time at which the CSM and the OSO exhibit equal linear velocities.

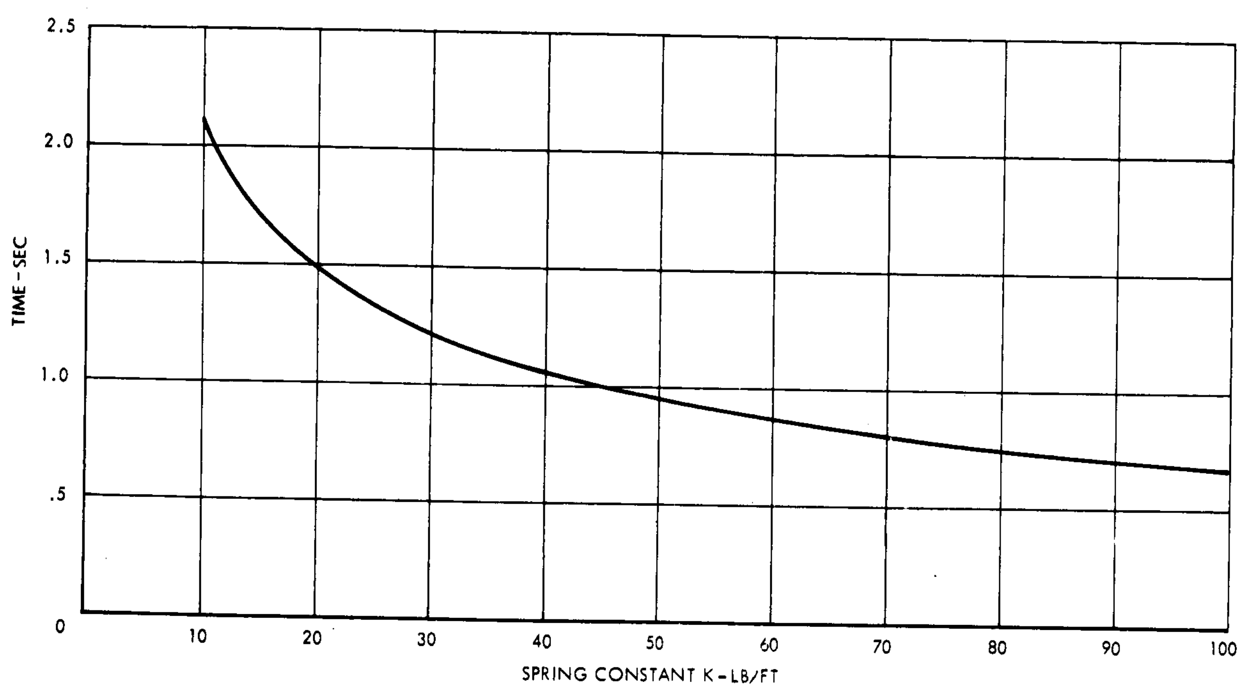

Fig. 4-9 Spring Compression Time for CSM-OSO Velocity Equalization

The spring energy required for velocity equalization as a function of the initial velocity differnetial is presented in Fig. 4-10. This energy is independent of the spring constant. Figure 4-11 shows the maximum attachment force as a function of initial velocity differential, for various values of spring constant. This force is due to the spring action of the structure and that of the capture mechanism spring forming a series spring combination. There is an oscillation of the mass centers about the average velocity at a frequency determined by the spring constant of the coupled structure and their combined masses. The magnitude of the oscillating coupling force is equal to the force required to fully compress the attachment mechanism spring. The maximum value reduces as time increases through structural damping of the system. Fig. 4-12 illustrates the magnitude of the force as a function of time for compression spring constants of K = 10 pounds per foot and 30 pounds per foot. The oscillatory forcing function assumed after the compression spring locks is illustrated by the dashed lines.

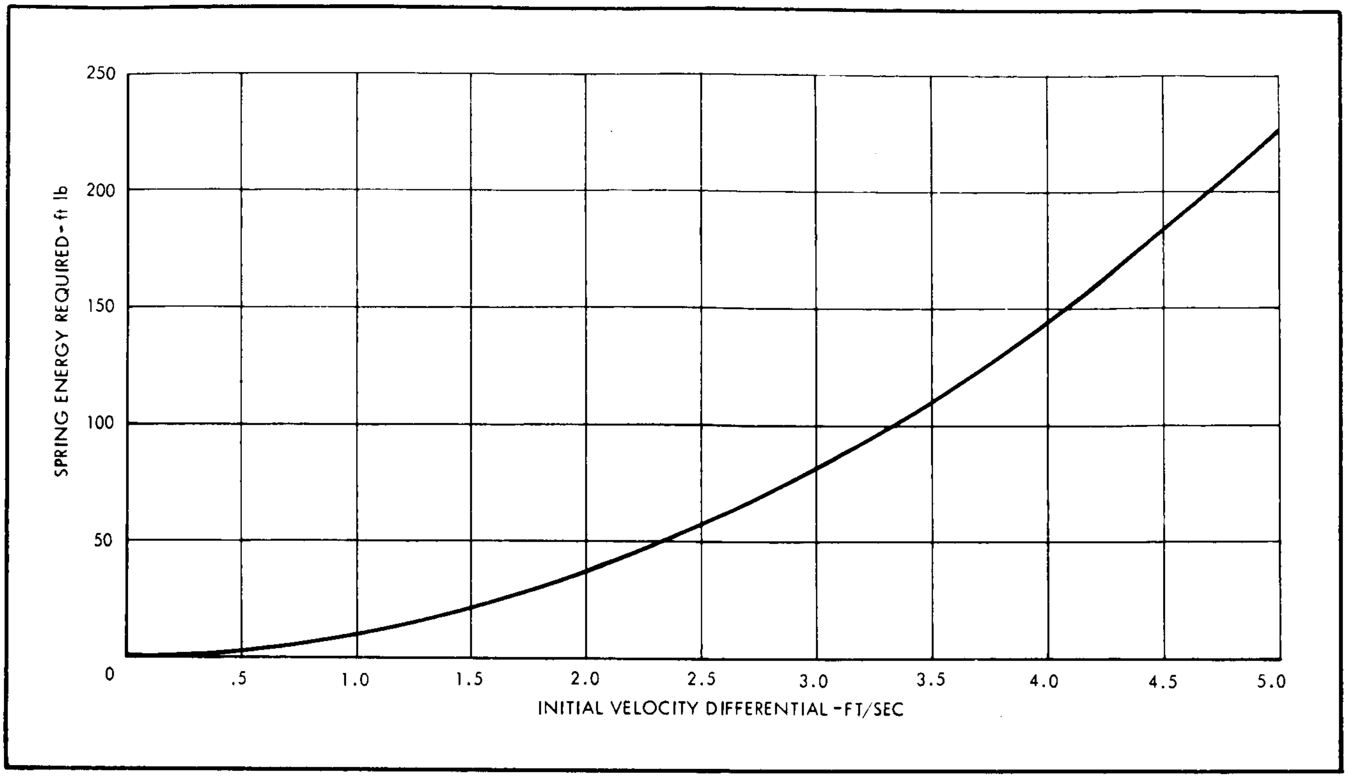

Fig. 4-10 Spring Energy Required for CSM-OSO Velocity Equalization

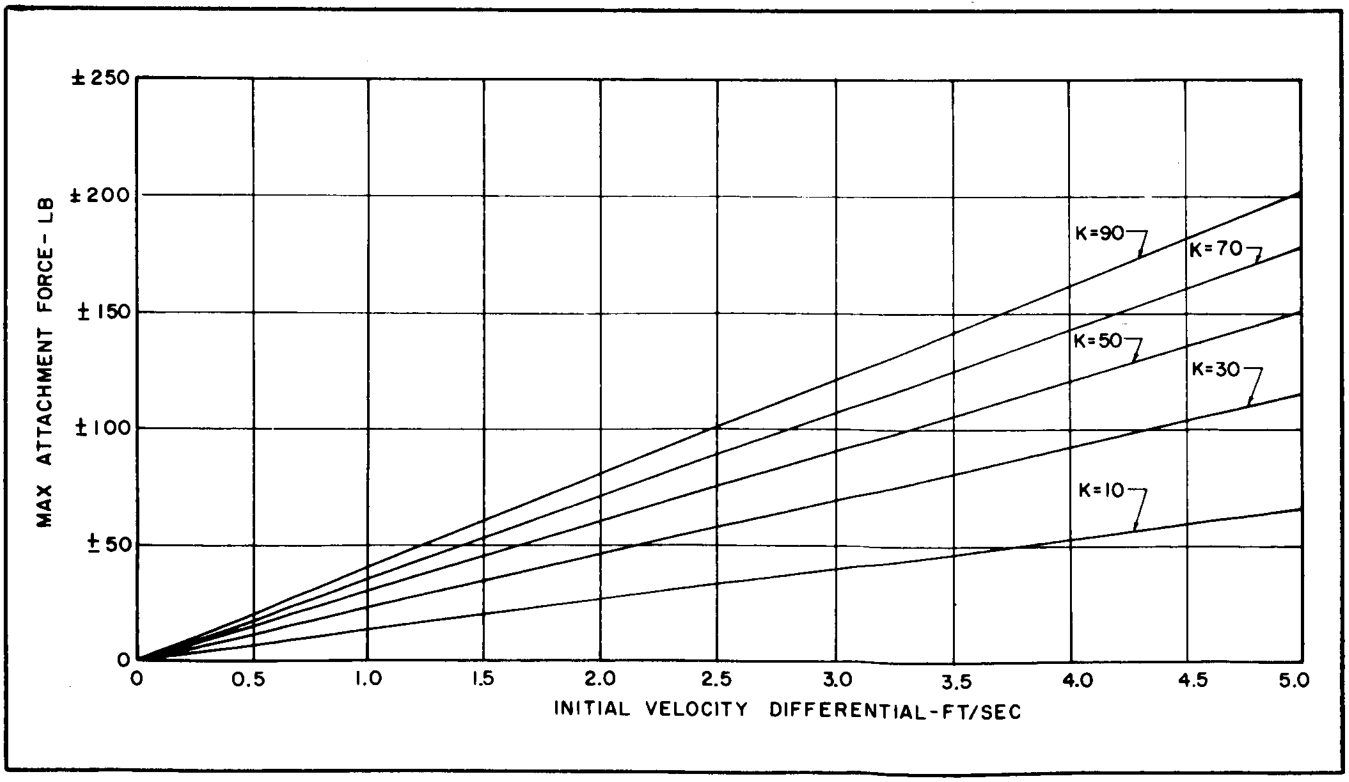

Fig. 4-11 Maximum Attachment Force

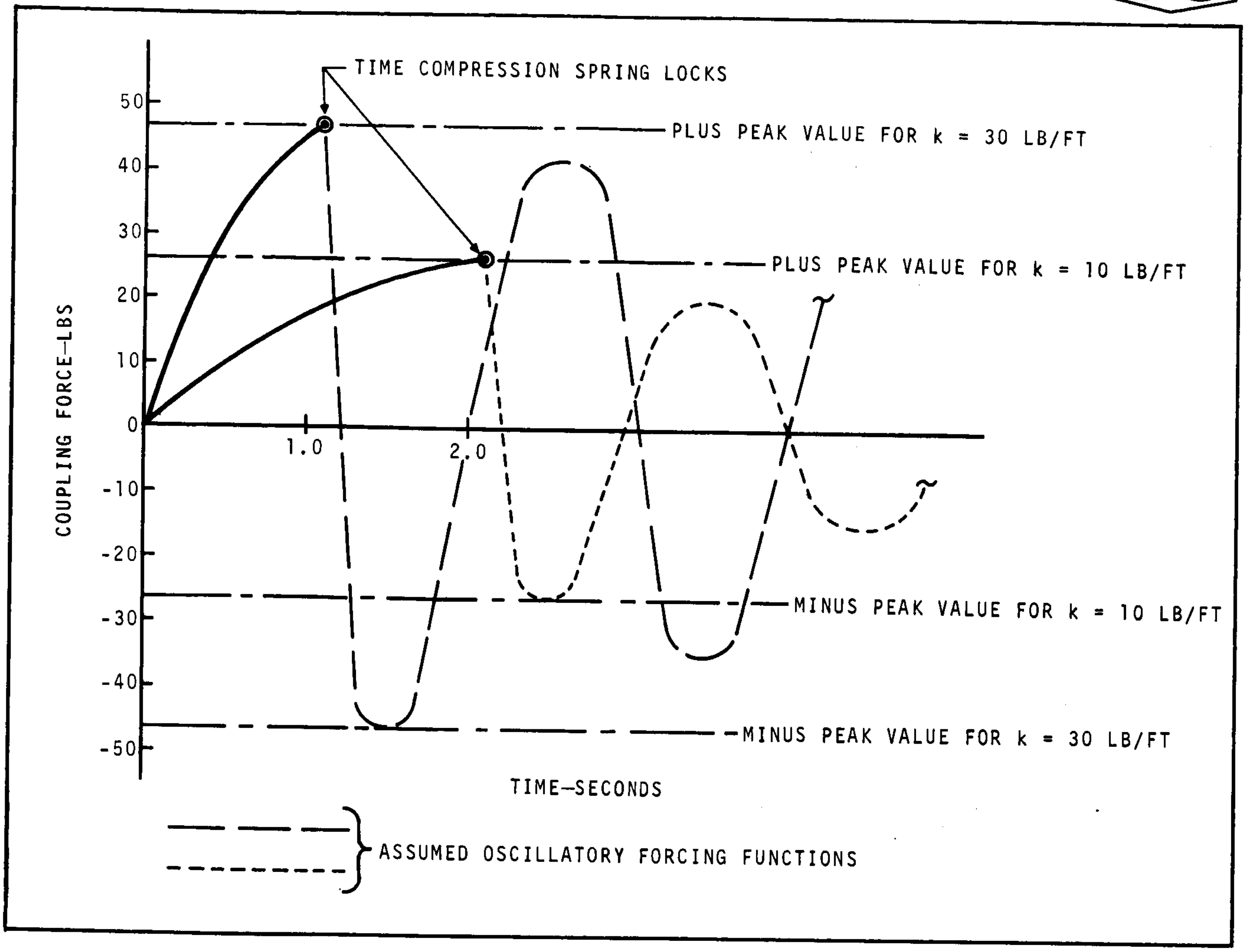

Fig. 4-12 CWP/OSO Attachment Forces

4.2.5.2 Rotational

The OSO consists of a spinning wheel, and a pointed solar array with an experiment package. The spinning wheel provides a stable platform from which the pointed section is referenced. The spinning mass provides the OSO with gyroscopic properties. Capture loads in line with the OSO spin axis produce pure translation of the mass, whereas capture loads applied with some eccentricity to the spin axis result in translation of the mass center as well as gyroscopic rotations of the OSO. An analysis has investigated the gyroscopic response of the OSO to an applied eccentric capture laod. Appendix D presents the mathematical model developed for this analysis.

The analysis is based on a capture load in line with the OSO spin axis but displaced some distance determined by the capture mechanism boom length and the dead band oscillation of the CSM. A maximum eccentric displacement of the capture load of ±2.7 inches is assumed with no angular misalignment. This distance is determined by the peak-to-peak excursion of the CSM longitudinal axis when the CSM is operating in its finest (±0.5 degree) control mode and does not include pilot misalignment error. The distance assumed from the capture head to the CSM center of mass is 25 feet. The eccentric displacement of the capture load produces a moment on the OSO equal to the eccentric distance multiplied by the capture load. As discussed previously in this section, the OSO satellite can be considered as four interconnected rigid bodies. The satellite is not symmetrical, and the actual response to capture forces depends on the orientation of the upper structure with respect to the eccentricity of the load. This orientation cannot be assumed to remain constant during the capture. However, about 90 percent of the OSO's inertia is in the wheel, and to simplify the analysis, the flexibly coupled sail and pointed experiments are assumed to make a minor contribution to the gyroscopic response of OSO to the capture loads.

The capture loads determined for colinear capture are assumed valid, since the small eccentricity does not permit the capture mechanism spring displacement to vary appreciably. Therefore, the forcing function or capture load remains essentially the same for the eccentric capture as for colinear capture. Further, the load is assumed to remain in the same plane throughout gyroscopic rotations of the OSO. For small angles, this approximation is valid.

For the assumptions stated above, and considering only the freely rotating portion of OSO, Euler angle displacements and rates are determined as a function of time. The maximum value of time considered is that time when the capture mechanism spring is fully compressed and locked. The angular rates at this time are those which must be reduced to zero along with the spin rate to complete capture of the OSO.

Data used in the analysis are:

m_A = 870 slugs - mass of CSM

m_O = 18.5 slugs - mass of OSO

K_B = 4.56×10^6 lb/ft - spring constant of boom

I_S = 30.4 slug ft^2 - moment of inertia of OSO about spin axis

I_T = 17.2 slug ft^2 - moment of inertia of OSO normal to spin asix

W_S = 30 rpm - OSO spin rate

R = 0.225 ft - capture load eccentric distance

Results are computed for initial values of closing velocity from 0.5 ft/sec to 5.0 ft/sec in steps of 0.5, and for capture mechanism spring constant values from 10 lb/ft to 90 lb/ft in steps of 20.

Figures 4-13 through 4-16 present the Euler angles θ and ψ as a function of time for spring constants of 10 lb/ft and 30 lb/ft for various values of contact velocity. Figures 4-17 and 4-18 show $\dot{\psi}$ as a function of time for spring constants of 10 lb/ft and 30 lb/ft for various values of closing velocity. Figures 4-19 through 4-22 show the value of Euler angle θ, $\dot{\theta}$, and Euler angle ψ, and $\dot{\psi}$ at the time the capture mechanism spring is fully compressed, as a function of closing velocity for various values of capture mechanism spring constant. Since the rotational rates of OSO about all three axes must be nullified to complete capture, it would be most efficient to restrict the build up of $\dot{\theta}$ and $\dot{\psi}$ by limiting the closing velocity for a given capture mechanism spring constant. The angular travel of the attachment head should also be designed such that the displacement of the Euler angles θ and ψ, at the time the capture spring is locked, is less than the angular limit of the head. This precludes an impact into the attachment head limit stops and thereby reduces perturbations of the dynamics and moments applied to the end of the boom. A value of 15 degrees is shown on the subject curves, which represents angular limits for the attachment head. It can be seen from the represented curves presented (i.e., Figs. 4-19 and 4-21), that angular displacements of 15 degrees or less for θ and ψ would be obtained with compression spring constants of 10 lb/ft or greater, and with closing velocities less than 2.5 ft/sec. Further, if a spring constant of 30 lb/ft is selected, it is seen from Fig. 4-11 that an initial differential velocity of 2.5 ft/sec, the maximum attachment force could be as large as ± 60 pounds. Also, from Fig. 4-9, the time for equalizing the CSM/OSO differential velocity with a spring constant of 30 lb/ft is approximately 1.25 seconds. As previously stated in paragraph 4.2.2.9, a bond of 10 psi is obtainable from commercially available adhesives less than one minute after application. Thus, with as little as six (6) square inches of adhesive area on the attachment head, adhesive forces can be obtained in less than one minute equivalent to the attachment force. Current investigation indicates that 100 square inches of adhesive surface area for bonding to the bottom of the OSO is easily obtainable by utilizing a segmeted adhesive attachment head.

As the attachment force is dissipated, θ and $\dot{\psi}$ go to zero, and the OSO spins about a new spin axis relative to the boom. Since the OSO is not a rigid body, some finite time is required to reduce the rotational rates $\dot{\theta}$ and $\dot{\psi}$ to zero. Therefore, some additional or overtravel occurs after the spring is locked and must be provided for in determining the angular limits of the attachment head.

4.2.6 Precapture Inspection

The OSO should be inspected prior to capture to determine if there are any hazards that could endanger the astronauts, or if any conditions exist that would preclude a successful capture. In addition, the OSO spin rate should be determined to facilitate the capture operation. Coincident with this inspection, documentary still and motion picture photographs of OSO would be taken.

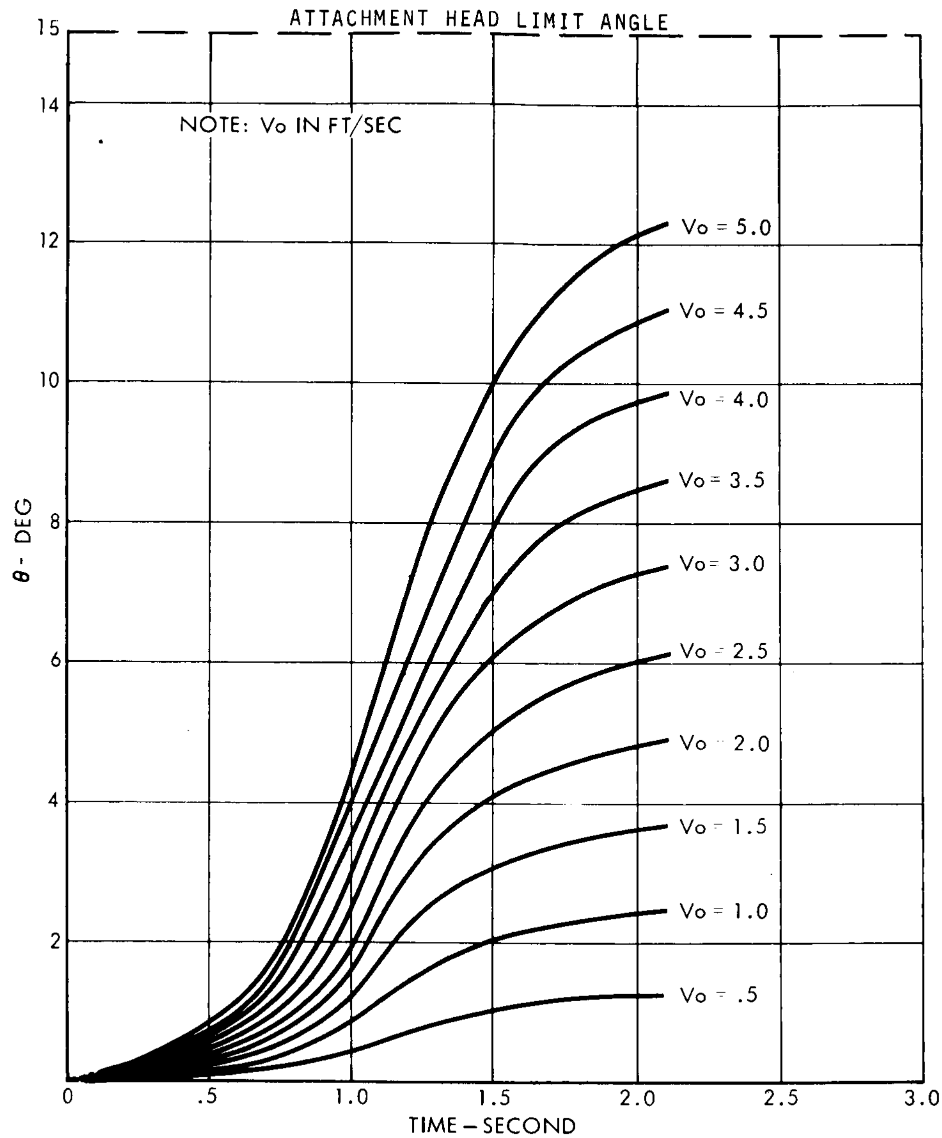

Fig. 4-13 Euler Angle θ vs. Time, (K = 10 lb/ft)

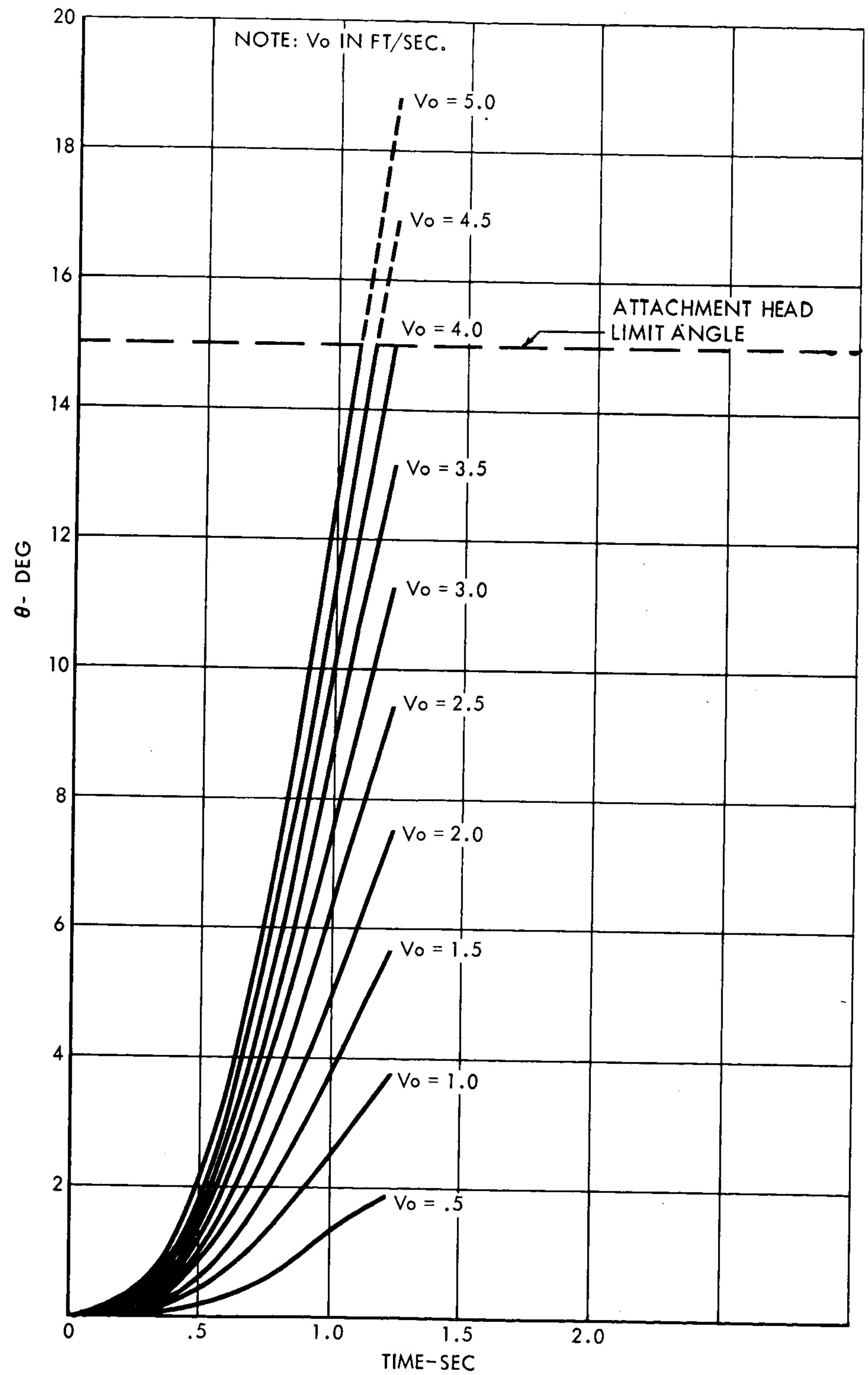

Fig. 4-14 Euler Angle θ vs. Time, (K = 30 lb/ft)

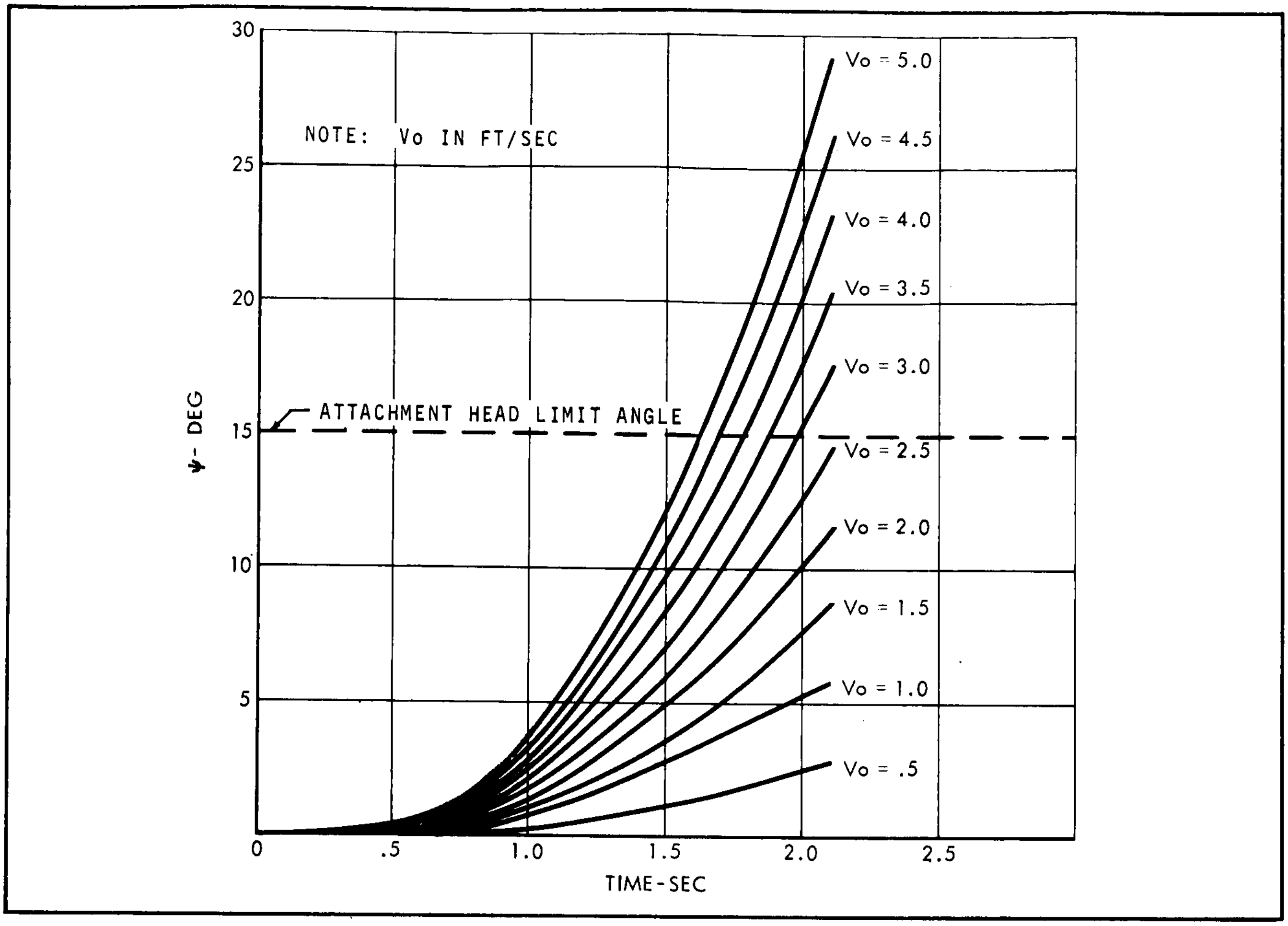

Fig. 4-15 Euler Angle ψ vs. Time, (K = 10 lb/ft)

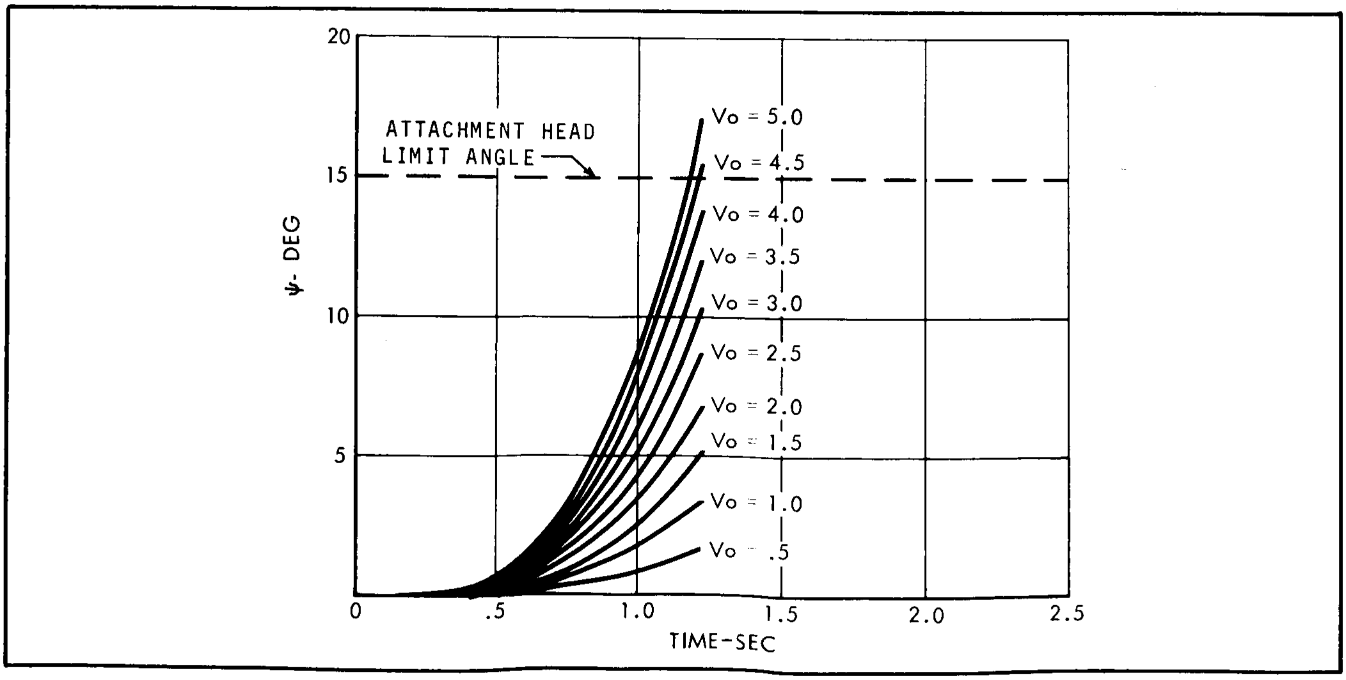

Fig. 4-16 Euler Angle ψ vs. Time, (K = 30 lb/ft)

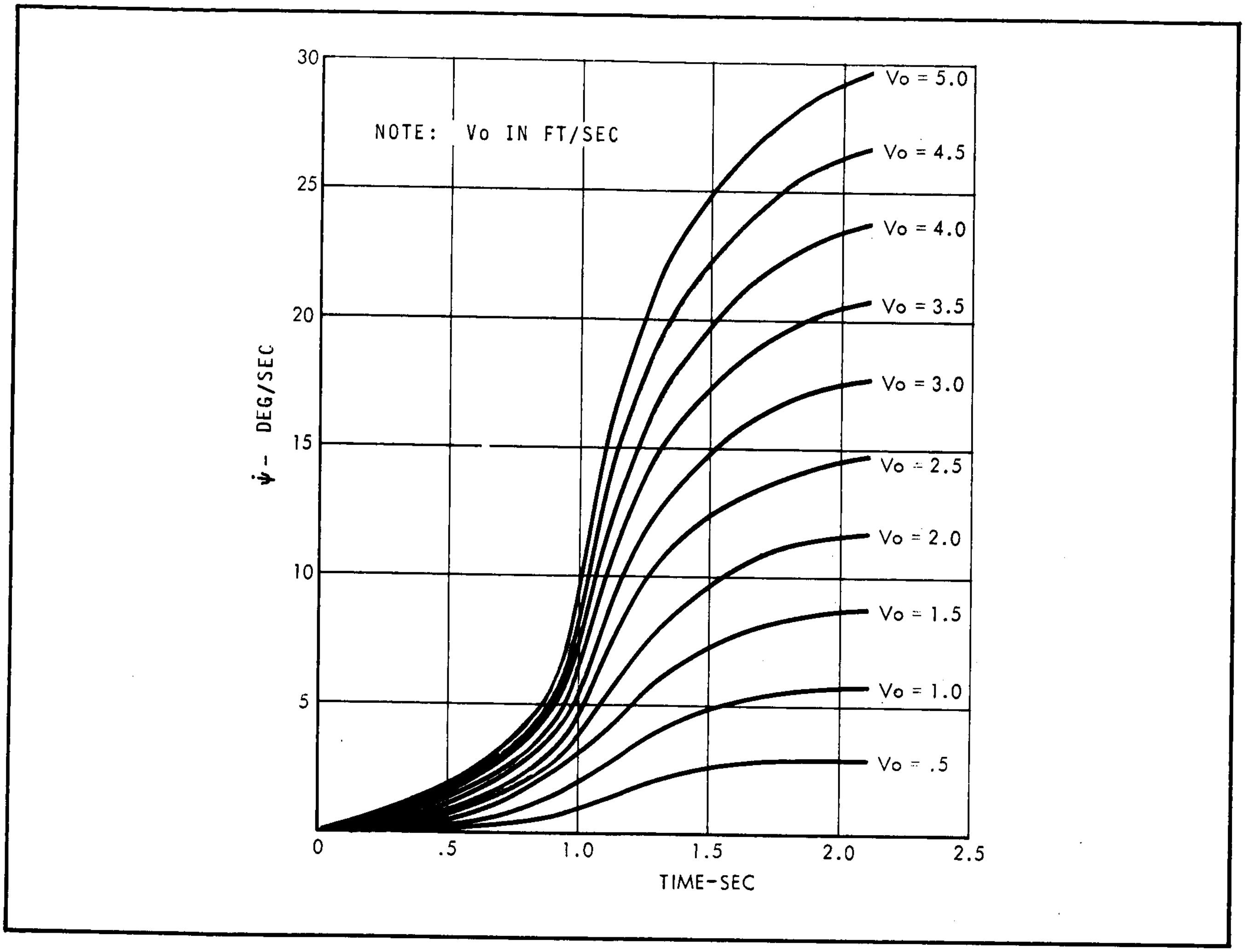

Fig. 4-17 $\dot{\psi}$ vs. Time, (K = 10 lb/ft)

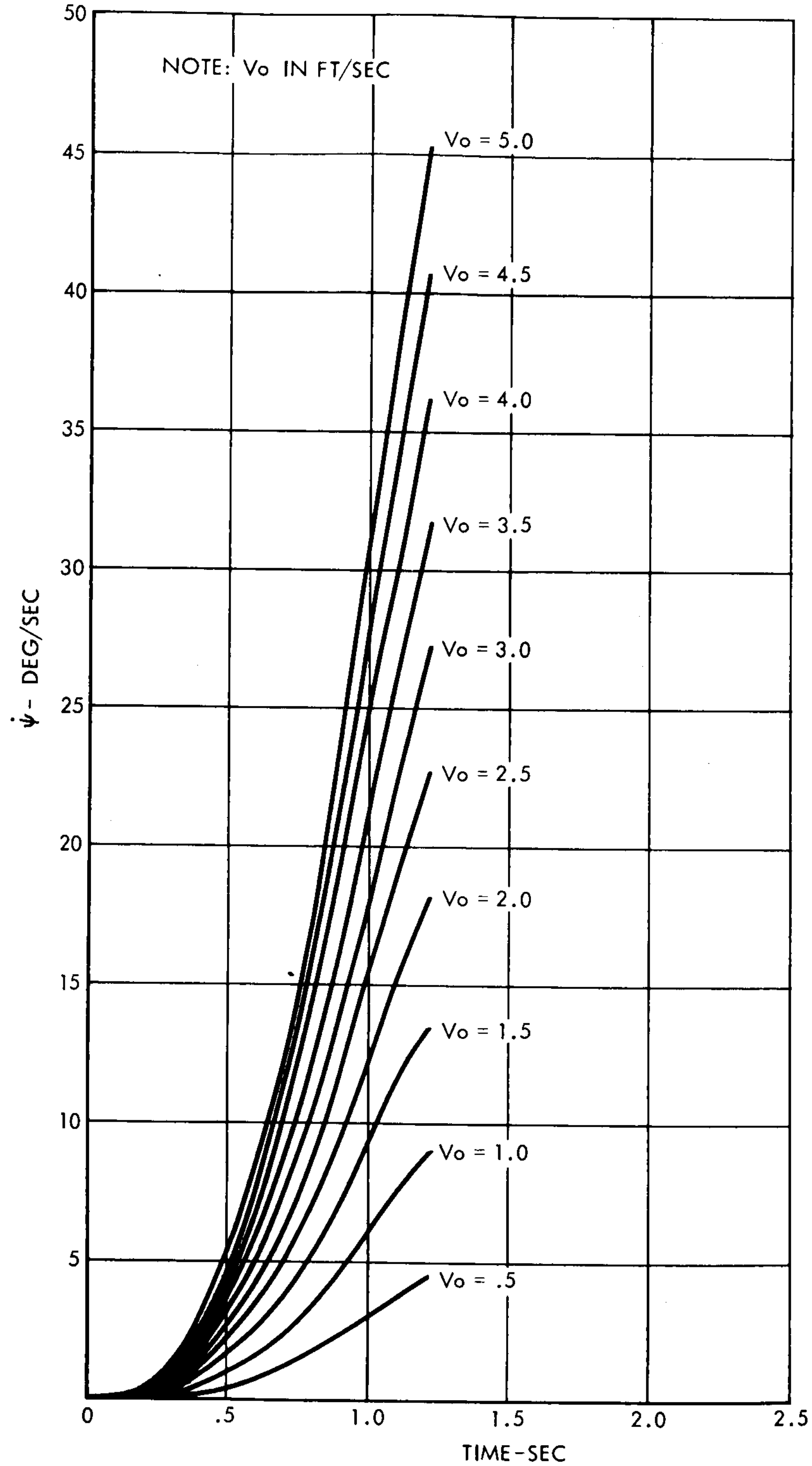

Fig. 4-18 $\dot{\psi}$ vs. Time, (K = 30 lb/ft)

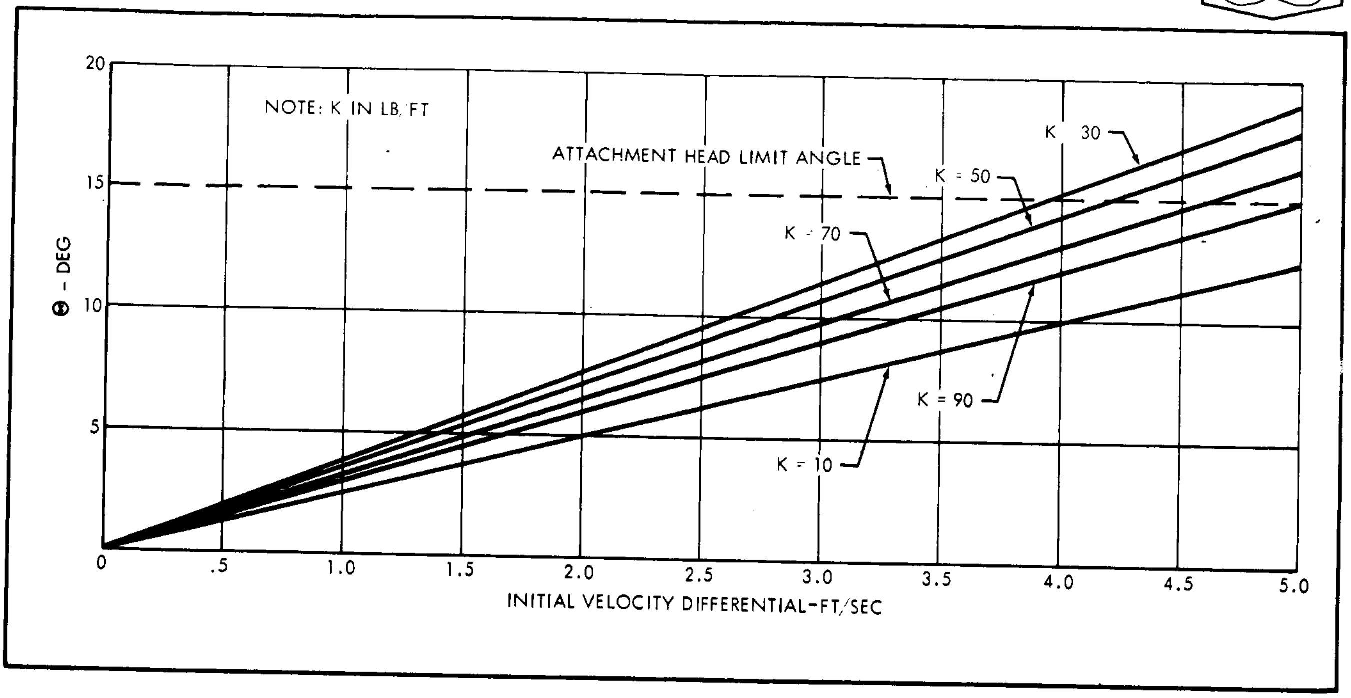

Fig. 4-19 Euler Angle θ for Maximum Spring Compression

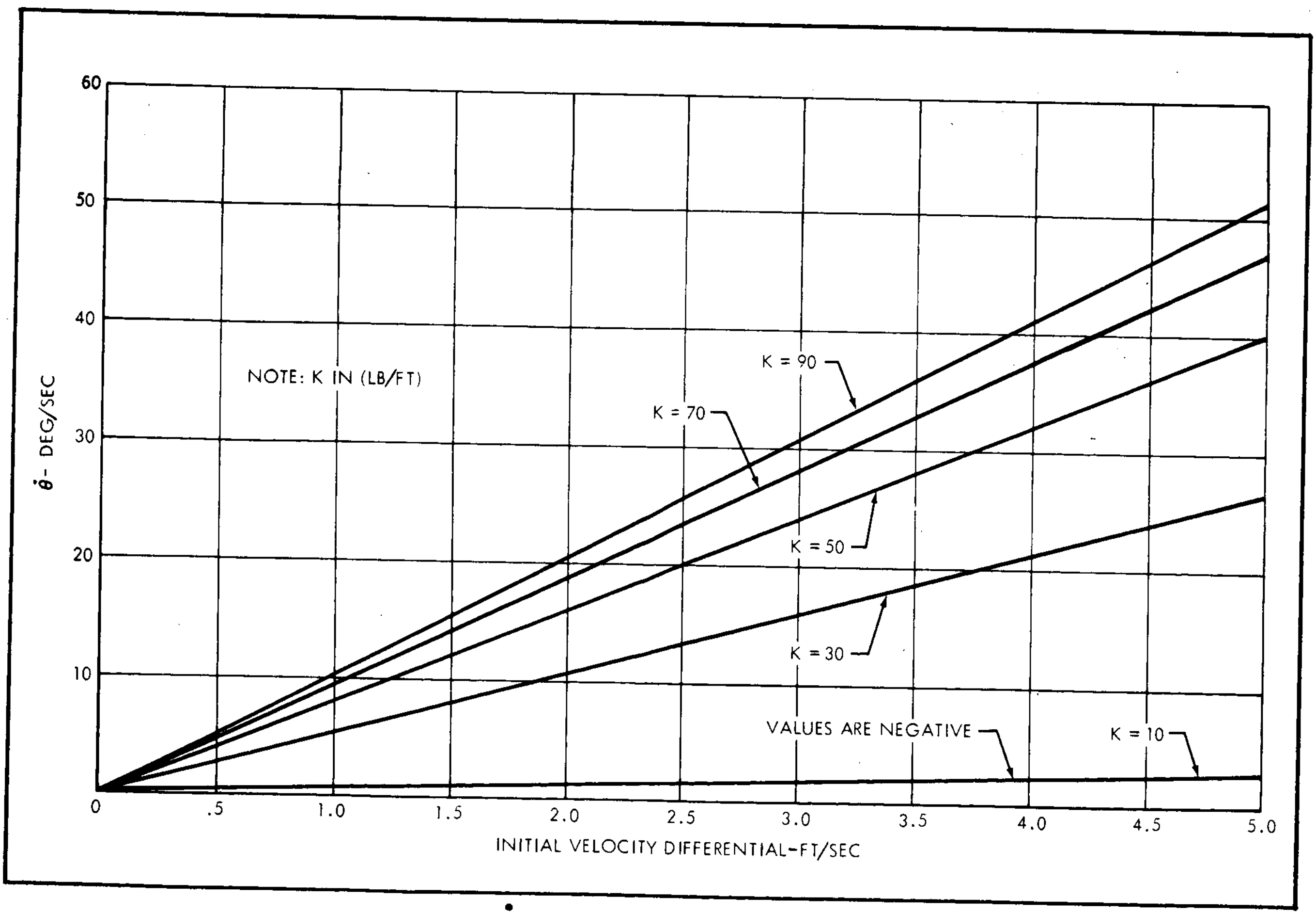

Fig. 4-20 $\dot{\theta}$ for Maximum Spring Compression

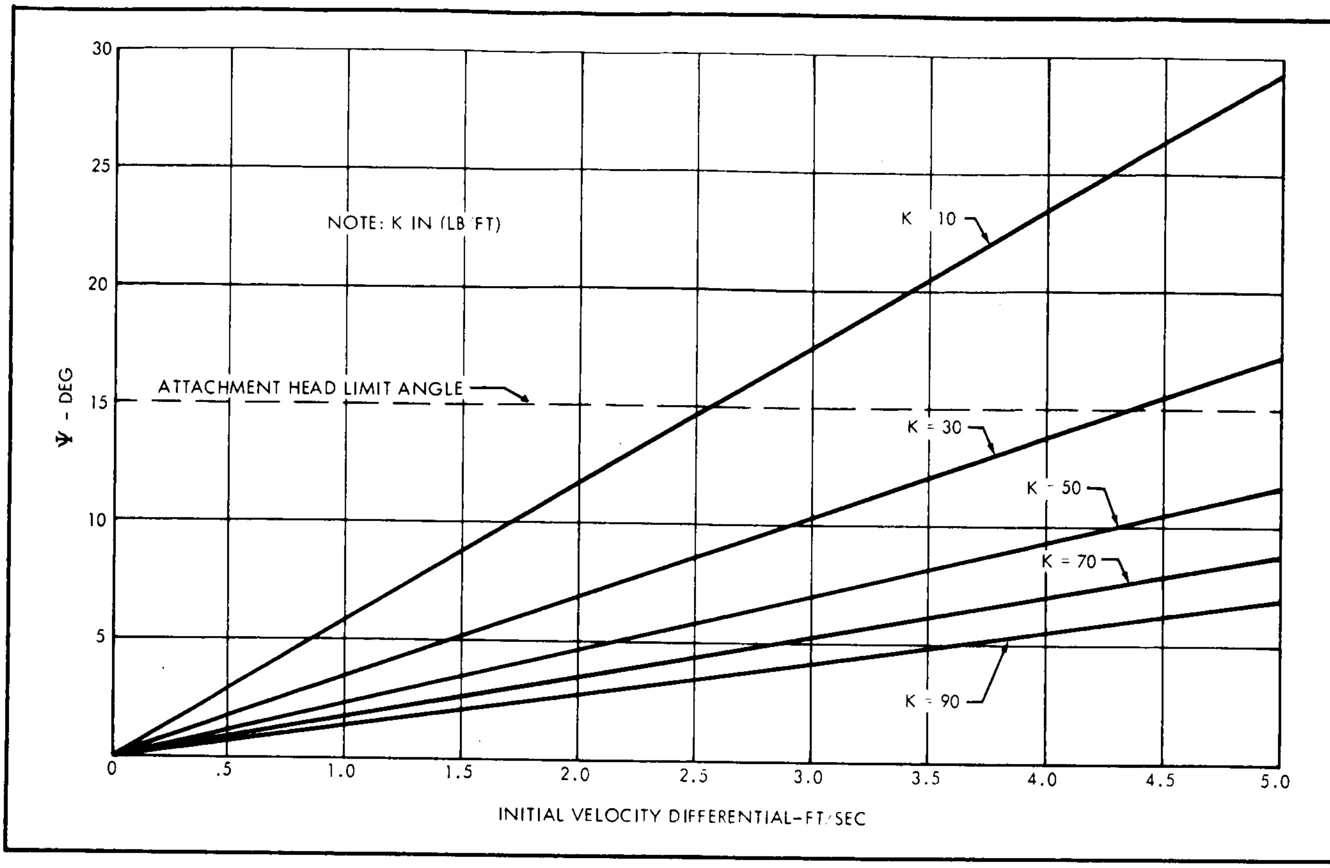

Fig. 4-21 Euler Angle ψ for Maximum Spring Compression

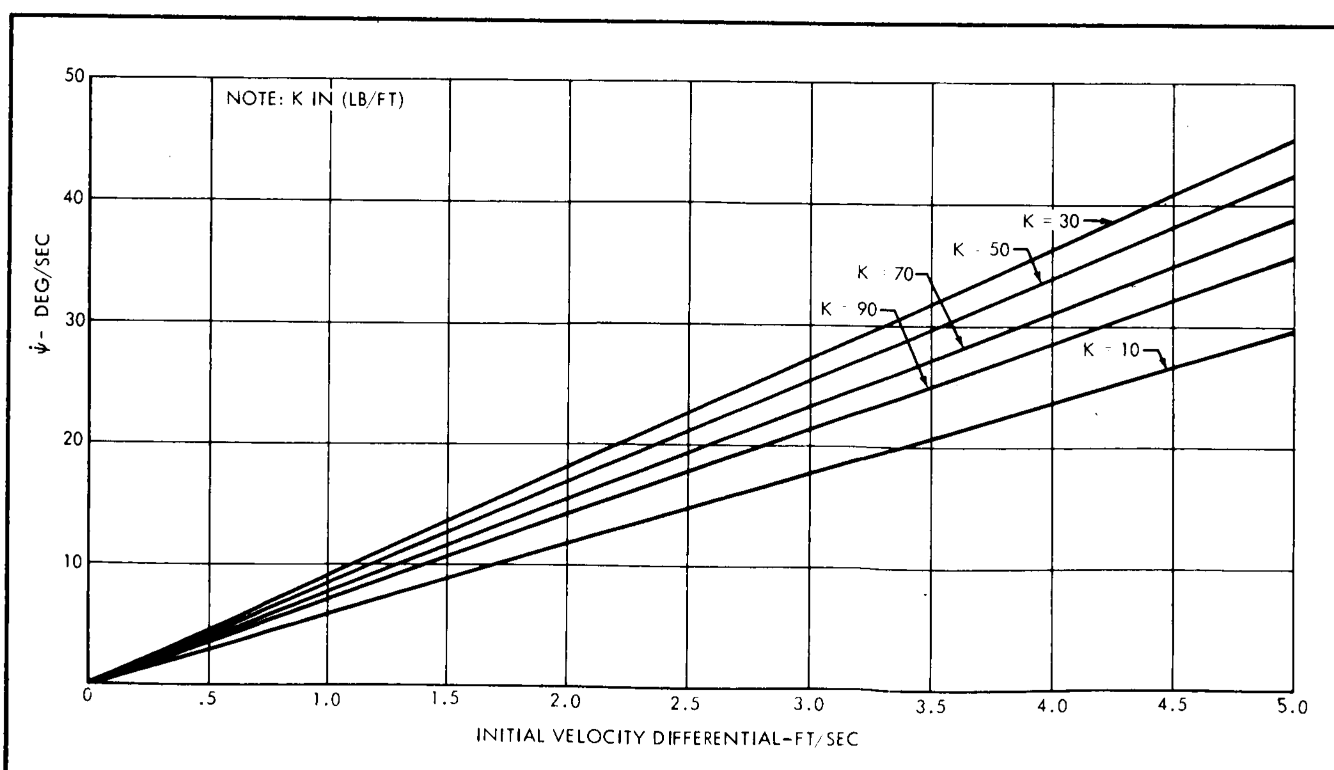

Fig. 4-22 $\dot{\psi}$ for Maximum Spring Compression

Structural damage to the OSO which could endanger an astronaut performing EVA is possible, although not probable. This damage might result from rupture of a pressurized gas container, meteoroid impact, or partial failure during last stage rocket separation. Any damage which might have occurred on an active OSO should be either identified or suggested by telemetered data. The presence and degree of hazardous structural damage would be determined by visual observation of OSO during circumnavigation. Another hazard to the astronaut is ionizing radiation from the OSO due to its exposure to the environment. The levels are to be measured prior to the EVA.

Excessive spin axis wobble or tumbing of OSO could impair successful capture. However, as discussed in Section 4.2.4, the OSO spin rate decays very slowly; even four or five years after the spin control has been inoperative, the satellite should still be quite stable. The OSO should not be subjected to any forces which could significantly alter its motion. However, it is desirable to visually evaluate any tumbling or wobble during circumnavigation of OSO. This can be accomplished by orienting the CSM along the OSO spin axis and observing the motion.

The spin rate of OSO should be approximately determined in order to rotate the attachment head before capture. This can be accomplished by inertially orienting the CSM longitudinal axis either approximately in the plane of the OSO wheel and normal to the spin axis or along the spin axis; the time for a number of revolutions of the satellite is then measured. A revolution of OSO can be distinguished by passage of a bright spot on the satellite, such as a blue flash from the solar cells. This must be performed during orbital day with the sunlight approximately behind the CSM.

4.2.7 Release Techniques

Release of the OSO can readily be accomplished with either the yoke or the adhesive capture mechanism. After release of the attachment head, the CSM can move away from OSO using the RCS thrusters. If the RCS exhaust gases are objectionable with respect to contaminating the OSO, the spring in the capture mechanism boom can be released to push the OSO away from the CSM; however, this method is not desirable, since it could significantly alter the OSO orbit. These methods function as follows:

(1) Yoke head: OSO release from the yoke mechanism would require release of the three mechanical latches on the centering mechanism attachment fingers. This would be the reverse of the capture procedure and could be utilized with either a spinning or nonspinning OSO.

(2) Adhesive head: After the centering mechanism has been attached to the OSO adapter flange, the adhesives can be released either by heat or solvents. However, application of solvents in a space environment is very difficult, and the application of heat is more practical. The adhesive attachment pad in the capture mechanism would consist of a plastic foam coated on both sides with adhesive to conform to minor surface irregularities. Two methods of heating can be used, although one is suitable for release of an OSO that is not to be respun (i.e., Mission 1).

When the OSO is not to be respun, remnants of the adhesive pad could be left on it. The pad could be fabricated of polyurethane foam containing a grid of resistance wire. Passing a current through the grid heats and decomposes the foam separating the OSO with adhesive and part of the pad attached.

When the OSO is to be respun, leaving the adhesive pad attached to the bottom of OSO might disturb the OSO balance. Therefore, heat would be used to release the adhesive from the bottom of the OSO. Since the proposed adhesives rapidly lose their strength at temperatures over 200 to 250°F, heat can be applied by a resistance wire grid, or by a material such as pyrofuze. A silicone foam pad would be used, which would not decompose under the higher temperatures. The quantity and rate of heat input depends on the heat loss to the OSO aluminum skin. However, this loss should be low because the adhesive is not a good thermal conductor; as it lossens, the poorer bond further decreases the thermal conductivity.

It is recommended that either the yoke arms or the adhesive be released as soon as the centering mechanism has been secured to the OSO adapter flange.

4.3 RECOMMENDED TECHNIQUES AND CONFIGURATION

The studies and trade-off analyses conducted have resulted in a recommended capture technique and configuration. A semirigid mechanism with a flexible head arrangement for contacting and containing the target OSO is to be located on the CSM docking adapter. Operationally, the astronaut crew would maneuver the CSM, with the capture mechanism docked to the nose, until the spinning capture head makes contact with the OSO. The OSO is then despun by means of a control feature in the capture head; this brings it into equilibrium with the CSM. The concept is compatible with the requirements for a work platform mounted to the main structure during the useful work phase. Additional details on the capture and release mechanisms and associated operations are presented in the following sections.

4.3.1 Capture Mechanism Configuration

The capture mechanism is depicted in Fig. 4-23, with the main features involving capture indicated. These are the docking collar, the boom, the translation spring, the flexible joint and spin control, and the attachment head. The capture mechanism docking collar mates to the Command Module at station 109, and it is to be patterned after the docking collar used on the LEM and S-IVB orbital workshop. The egress/ingress structure supports the main structural boom. This structure could be telescoped for stowage in the Service Module Sector I if required. The structural boom extends the attachment head about 15 feet from the CM docking collar. This enables the astronaut crew to see the attachment head (the limit of their line of sight is 7.5 feet along the center line from the docking adapter station) while aligning for contact with the OSO.

The entire configuration (i.e., capture mechanism and work platform) is referenced frequently in the balance of this report as the Capture Work Platform (CWP). (See Section 5.2.2.)

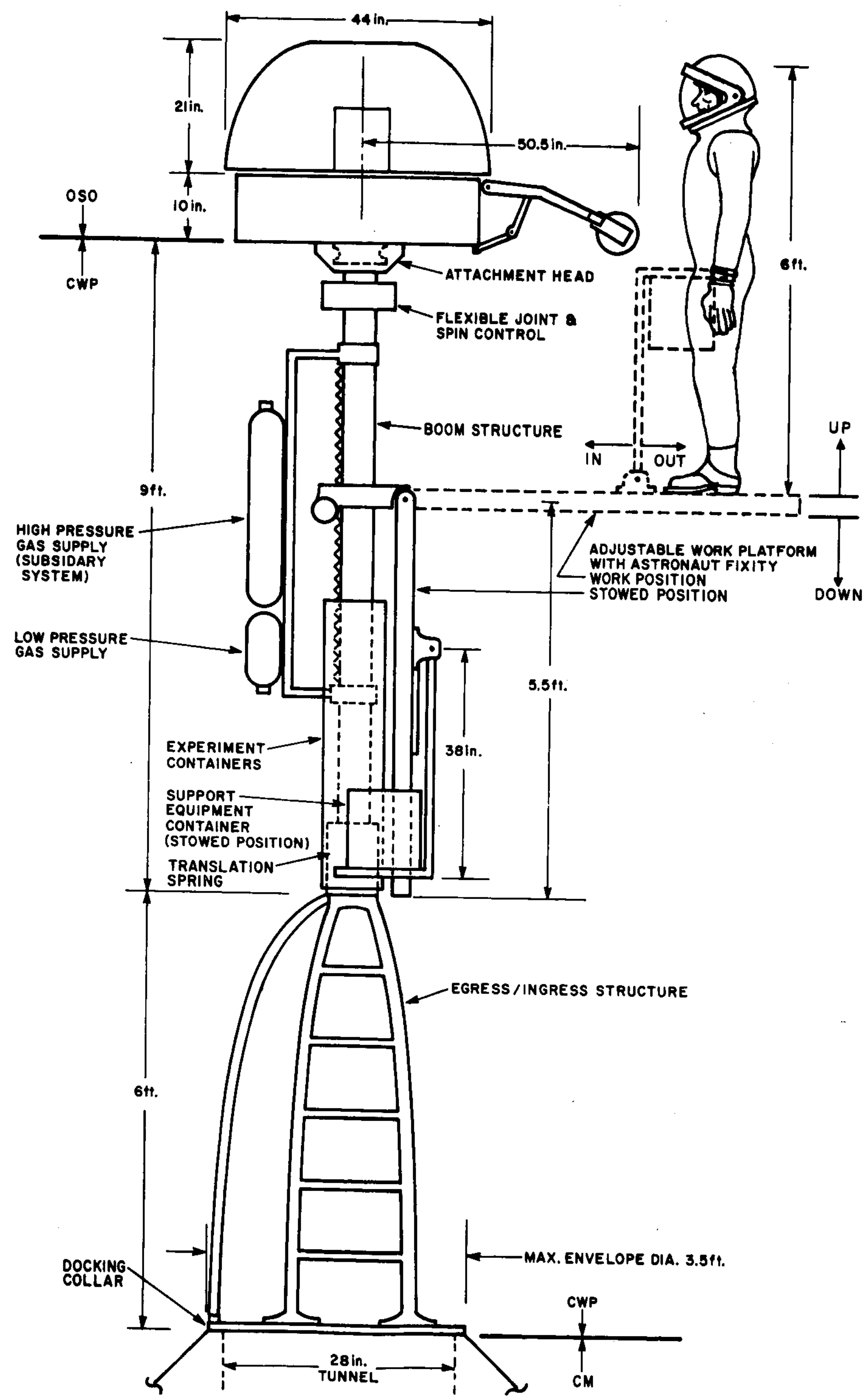

Fig. 4-23 Capture Work Platform Conceptual Configuration

Within the boom is a spring for absorbing the translational energy from the contact of the capture mechanism with the OSO. The spring is compressed as a function of the selected spring constant and the differential velocity at contact. Locking grooves would be provided in the wall of the spring housing to lock the upper or piston part of the boom when it has compressed the spring.

The controlled spin axis provides for spin-up of the attachment head prior to contact with the OSO (for release) and to despin the OSO when it is locked onto the attachment head. This controlled spin axis may be a gimbal and torque motor, or it may be a friction-drive floating plate. Either mechanism can be designed to compensate for off center alignment between the boom axis and the OSO spin axis when contact is made. The OSO spin angular momentum would be nullified by applying torque to the gimbal motor, or by applying force normal to the floating plate.

The attachment head connects to the spin gimbal or the floating plate similar to an adaptive head. That is, the specific type head to be used can vary depending on the satellite to be captured. As indicated in the trade-off study, either the yoke or the adhesive head can be used to capture an OSO. A yoke head would have three arms that would insert through the space between the OSO arms and clamp over the OSO arms to contain it. The adhesive head would be a ring of vinyl foam with an adhesive coat on both sides. One adhesive side would hold the foam to the head structure and the other side would adhere to the OSO upon contact.

Incorporated in the attachment head would be a manual centering mechanism. At the start of the EVA operations, the astronaut would release a lug assembly to engage the adapter on the bottom of the OSO. These lugs would be spring loaded so that the manual operation of a cam would center the OSO in the attachment head. The attachment head would be centered on the boom if the gimbal is used. If the floating head concept is used, it would be centered on the boom by an annular piston that would be driven against the head. During the centering operation, the yoke arms or the adhesive would be released to facilitate the centering. Force could be applied to the adhesive ring in shear to separate it from the OSO, or the adhesive could be heated by passing current through a michrome wire embedded in the adhesive. The adhesive loses its holding strength above a specified temperature.

Following the centering operation, the yoke arms or the adhesive ring would be removed from the attachment head by extracting pins and jettisoned. Release of the OSO would then be accomplished by additional rotation of the cam to drive the retaining lugs away from the OSO adapter ring. This action could be performed electrically by control from the CM.

4.3.2 Operational Procedure

The CSM would dock with the capture mechanism in its stowed location in the SLA; this is similar to the CSM/LEM docking maneuver.

After rendezvous and station keeping and just prior to capture, the attachment head is spun-up to the rate of the OSO as determined during precapture inspection. This reduces the shear loads introduced into the attachment head of the OSO during the contact phase.

To accomplish the capture of the target OSO, the astronaut crew aligns the CSM so that the capture mechanism is pointed at the bottom of the OSO wheel. The CSM would then be translated toward the OSO with the crew maintaining the CWP boom axis as near to coaxial with the OSO spin axis as possible. This translation and alignment is continued at a differential velocity less than 2 ft/sec until contact is made with the bottom of the OSO wheel. Any pitch or yaw angular misalignment between the boom axis and the bottom of the OSO wheel is adjusted for in the flexible joint in order to bring the attachment head into full contact with the OSO.

After contact with the OSO has been established and the translation energy has been absorbed by the spring, the OSO is despun by driving the torque motor or braking the floating head. The OSO spin angular momentum is reduced by this action until kenetic equilibrium is reached between the OSO and the CSM. The attachment mechanism would then be locked so that the OSO is rigidly attached to the CSM. The OSO sail section continues to spin for several minutes until the bearing friction nullifies its spin angular momentum.

Upon completion of the EVA useful work experiment tasks, the CSM would be maneuvered to enable the OSO sun sensors to acquire the sun. The OSO systems would be activated and the attachment head spun-up until the OSO automatic spin control takes over. The OSO pointing control system would then be active, and the OSO could be released by operating restraining lugs in the attachment head. The CSM would separate from the OSO by operation of its RCS thrusters.

Post release inspection would be performed from a station keeping position to verify the operating condition of the OSO. The astronaut crew would then jettison the Capture Work Platform by undocking from it.

SECTION 5

USEFUL WORK

Section 5
USEFUL WORK

The useful work technical studies are discussed in this section. The useful work phase of the mission involves the operations following capture that are performed on the OSO satellite. These operations are the performance of experiment tasks on the OSO that include inspection, material retrieval and refurbishment. The tasks are to be conducted primarily under EVA conditions and are to be evolutionary over a series of three missions. A large number of experiment areas have been examined and are discussed in this section. The specific tasks for each mission are presented in Sections 6, 7, and 8. The various techniques to be used to perform the EVA tasks as well as the support equipment requirements have been analyzed. The recommended approach is presented following the detailed trade-off and technical discussion. Also included in this section is discussion of the training aspects necessary for this type of mission.

5.1 GENERAL CONSIDERATIONS.

The general considerations that have significantly affected the useful work studies are presented in this section. These include (1) criteria and constraints, (2) functional requirements, and (3) approaches considered.

5.1.1 Functional Requirements

The functional requirements for the useful work phase are established by analysis of function 2.4 on Fig. 2-3. This function is detailed in Fig. 5-1 to indicate the main subfunctions and the flow logic of performing useful work. The useful work function consists of five main functional efforts; (1) Function 2.4.1 "Post Capture Inspection"; (2) Function 2.4.2 "Modify-Refurbish; (3) Function 2.4.3 "Retrieve Material"; (4) Function 2.4.4 "Perform Calibration – Alignment"; and (5) Function 2.4.5 "Perform In-Orbit Checkout".

Each of these functional operations has been functionally analyzed in more detail, which is shown in Appendix E.

The "Post Capture Inspection" function is performed at the OSO to determine its condition. Note that all useful work operations involve EVA effort shown in Fig. 5-1 as Function 2.6. Following the preparation for the detailed tasks and the inspection, either the "Modify Refurbish" or the "Retrieve Materials" function is performed. These are followed by either or both the "Perform Calibration-Alignment" and the "Perform In-orbit Checkout" functions. At any time during these operations, the flow can go to mission control if problems arise as indicated by the "Correct Malfunction (CM)" function. At the completion of the experiment tasks, the flow goes to the "Release" function.

5.1.2 Approaches Considered

Evaluation of the functional requirements for the useful work phase has determined that several major alternative approaches can be utilized. The following approaches have been examined (Section 5.2):

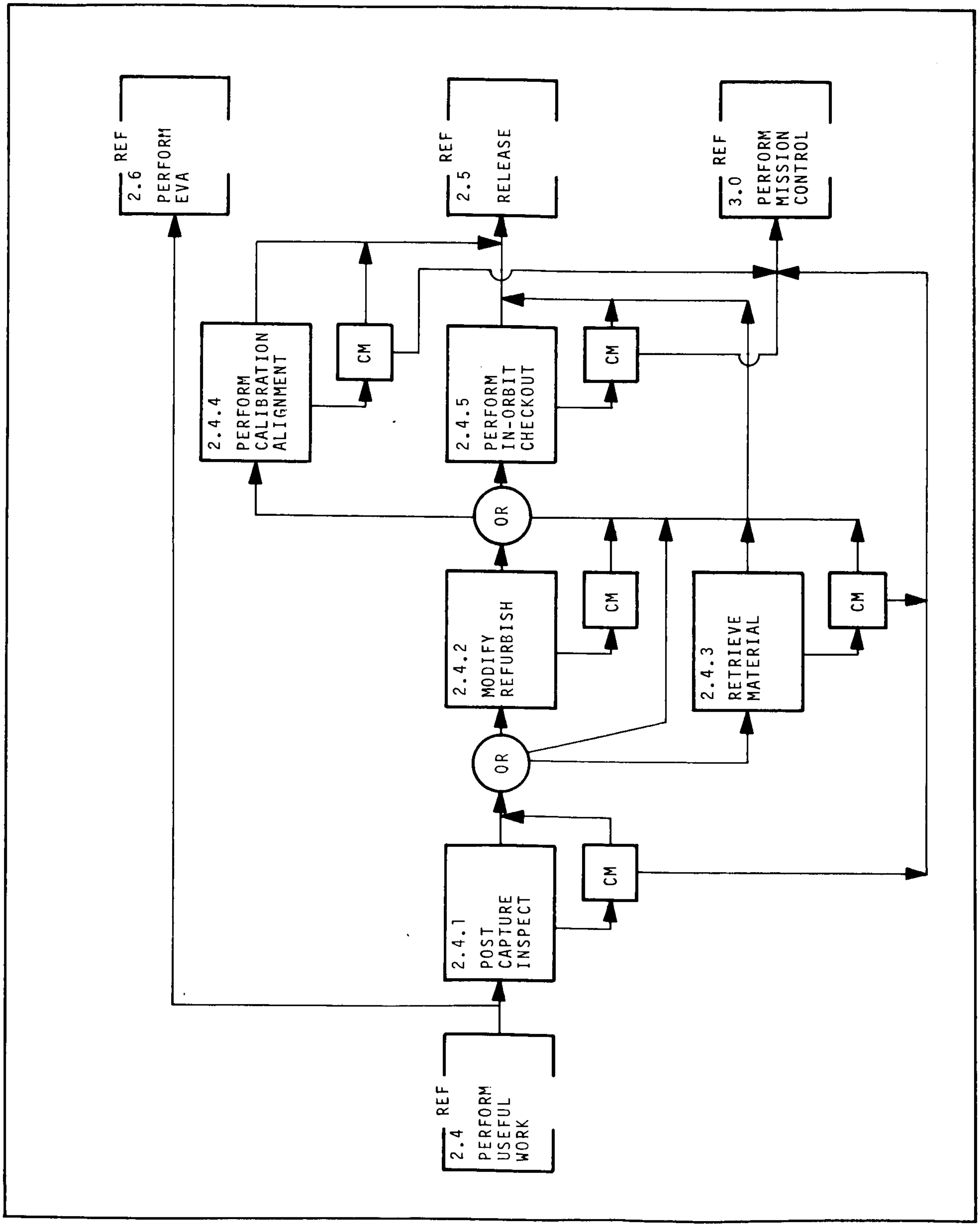

Fig. 5-1 Perform Useful Work - FFD

- Captured OSO rigidly attached to the CSM versus tethered to or free from the CSM

- Stationary work platform with movable OSO versus rigid OSO and astronaut movement about the OSO work areas

- Material recovery from exterior of OSO, rather than from the interior of the OSO compartments

- Refurbishment of OSO by replacement of parts or subsystems, rather than external addition of new parts or subsystems

- Checkout following refurbishment by means of the CSM on-board checkout system (OCS), rather than utilization of the OSO ground stations

In addition to the above approach alternatives, each of the major experiment categories has been studied to determine the tasks to be performed on the three missions. The OSO subsystems and scientific experiments have been analyzed for the key features (that can be refurbished) or for material retrieval. Any modification to the OSO or scientific experiment design that might be required has also been examined. Analyses have been conducted on the tool and support equipment requirements as well as on the training aspects of the mission effort. The compatibility of the useful work requirements with the capture mechanism configuration has also been examined. The experiment tasks have been formulated for the three missions, and time line analyses have been prepared for each mission. The results of these studies are presented in the following sections.

5.2 TECHNICAL STUDIES

The technical studies that have a major effect on the useful work phase of the mission are discussed in this section. These are the location of the OSO satellite during the useful work phase and the work station configuration. (The studies of the experiment categories and EVA requirements are presented in later sections.)

5.2.1 Location of the OSO

The location of the captured OSO for the useful work phase, has a significant effect on the ease of performing the experiment tasks and therefore on the amount of EVA effort that can be planned. The major alternatives are: (1) to locate the OSO rigidly attached to the CSM; (2) to attach the OSO on a tether to the CSM; and (3) to keep the OSO free from the CSM and maintain a station keeping relative position.

The specific location of the OSO on the CSM is dictated largely by the post capture useful work mission requirements, both for performing useful work experiments on the OSO, and for performing other operations of the mission profile. Since the complete mission profile is unknown at this time, the location of the OSO is primarily determined by the ease of performing the useful work tasks, and associated operations.

The recommended location and coupling of the OSO for useful work is to rigidly attach it to the CSM. The major advantages for this are that rigid attachment of the OSO to the CSM accomplishes the following:

- Provides for direct transfer of the EVA astronaut from the CSM to the OSO by means of hand holds and rails
- Maintains the OSO rigid with respect to the CSM for direct orientation between the OSO and the CSM, as a single configuration (This provides for inertial orientation of the OSO for visibility and thermal control by means of the CSM stabilization and control system.)
- Permits the orientation of the OSO for sunlight visibility and for thermal control
- Enables the EVA astronaut to work with a minimum length tether to the CSM
- Provides maximum ease for the EVA astronaut to move between the work site and the CSM cabin (since he can maintain direct hold on transfer hand rails)

The significant disadvantages of the tethered or free configuration are:

- Control of the tether and OSO dynamics during the performance of useful work tasks, would require an auxiliary stabilization system on the capture mechanism.
- Station keeping with a free or tethered OSO would require a significant amount of CSM maneuvering and crew time.
- Longer EVA astronaut tether adds complexity in the operation due to the relative dynamics between the two tethers and the CSM, or else it requires the use of a portable life support system (PLSS).
- Movement of the EVA astronaut to the OSO and return to the CSM cabin requires a soaring or a controlled flight, using an astronaut maneuvering unit (AMU) type system.

The capture system is to be located on the CSM docking adapter as described in Section 4. It will capture the OSO by contact and containment from underneath the wheel section, which will leave the sail and the major portions of the wheel exposed, following capture. The capture mechanism can be rigidized to provide the required rigid attachment of the OSO to the CSM for the useful work phase. Therefore, leaving the OSO on the capture mechanism for the useful work phase is recommended since it has several advantageous features as follows:

(1) The OSO does not require change from the captured position to some other attachment location on the CSM.

(2) The capture mechanism supports the OSO in a rigid manner, which can be easily adjusted to facilitate access to the OSO. Access to the OSO to perform the work tasks is good in the captured configuration, and the OSO can be rotated as required through the capture mechanism spin axis degree of freedom.

(3) The OSO can be easily reached during EVA by hand holds or rails along the capture boom.

(4) The OSO would be in view of the cabin during the EVA effort for surveillance of the operation by the crew members in the cabin.

(5) The effects of operation of the RCS thrusters on either the EVA astronaut or the OSO would be acceptable due to the approximate 25 feet separation.

5.2.2 Work Station

The performance of the useful work tasks is influenced by the type of work station established for use by the EVA astronaut. The major alternatives are: (1) to provide a stationary work platform attached to the capture system, with rotation of the OSO to the vicinity of the astronaut; or (2) to move the astronaut about the OSO work areas.

The recommended work station concept is to provide a stationary work platform for the EVA astronaut; this has the following major advantages:

- Enables the EVA astronaut to fix himself to a rigid platform to facilitate performing the experiment work tasks

- Permits locating the support tools, parts to be added, and storage for parts removed in easy access to the EVA astronaut

- Improves EVA time utilization for performing work tasks, since the OSO work area can be rotated to the astronaut without requiring him to change his fixity with respect to the OSO

Based on the conclusion that the useful work is performed on the OSO attached to the capture mechanism, a work platform configuration has been conceived to attach to the capture boom in proximity to the captured OSO. This work platform would remain on one side of the capture boom and the OSO, and the EVA astronaut would be fixed to it with waist and/or foot restraints. The OSO would be rotated to the position of the EVA astronaut, by releasing the brakes on the capture spin mechanism.

The primary purpose of this work platform is to provide fixity for the EVA astronaut while he is performing the experiment work tasks. In addition, it can be used to position the EVA astronaut in the most advantageous position with respect to the area of work on OSO; this enables him to conduct the effort in the most efficient manner. This would be provided by mechanisms which would translate the EVA astronaut parallel to the boom and radially with respect to the boom. The translation parallel to the boom would permit work on the OSO, both underneath it and on top of it. The radial translation would enable the EVA astronaut to move outside the circle of the OSO arms to rotate the OSO, and to move inward next to the wheel structure of the OSO for the work operations.

The work platform is shown extended in the frontispiece to this report and in Fig. 4-23. The entire configuration shown in Fig. 4-23 includes the systems that are required for the capture as well as for the useful work operations; this configuration is referred to as the Capture Work Platform (CWP). The work platform would be stowed next to the boom as shown in Fig. 5-2a until the EVA operations started. Upon egressing from the CM tunnel, the astronaut would extend the fixity structure perpendicular to the base as shown in Fig. 5-2b. He would then erect the platform base perpendicular to the boom as shown in Fig. 5-2c.

The astronaut would attach himself in foot restraints to a movable sled that can translate in and out on the platform base.

Controls for operating the translation mechanisms would be located on the fixity structure; however, the entire platform could be moved manually by the astronaut. The tools and support equipment required for the work tasks would be located in containers on the fixity structure. Large storage and supply containers would be mounted on the boom and would be reached by moving the platform to their vicinity.

With the CWP holding the OSO in a fixed position throughout the useful work phase, a thermal problem arises. The OSO is designed to balance the thermal input from the sun coming in the wheel rim panels periodically while they rotate, and the thermal dumping out the top and bottom of the wheel to deep space. With the stopping of the wheel for useful work, the side of the OSO wheel facing the sun increases in temperature, and the opposite side decreases. In direct sunlight, this temperature gradient reaches levels beyond the design limit of the OSO systems within a few minutes after stopping the wheel. Therefore, to maintain the temperature in the OSO within acceptable limits, the CSM/CWP/OSO configuration must be periodically rotated with respect to the sun. This can be accomplished by aligning the configurational long axis normal to the line-of-sight of the sun and then slowly rolling it by operation of the RCS thrusters.

5.3 INSPECTION EXPERIMENT TASKS

The useful work experiment program includes a variety of tasks that can be classified as inspection. These include (1) prerequisite, (2) documentation and (3) investigation. Some of the prerequisite tasks have been previously discussed in Section 4, since they are required to perform the capture operation. All of the inspection tasks are to be performed in orbit. The following discussions cover that part of the missions.

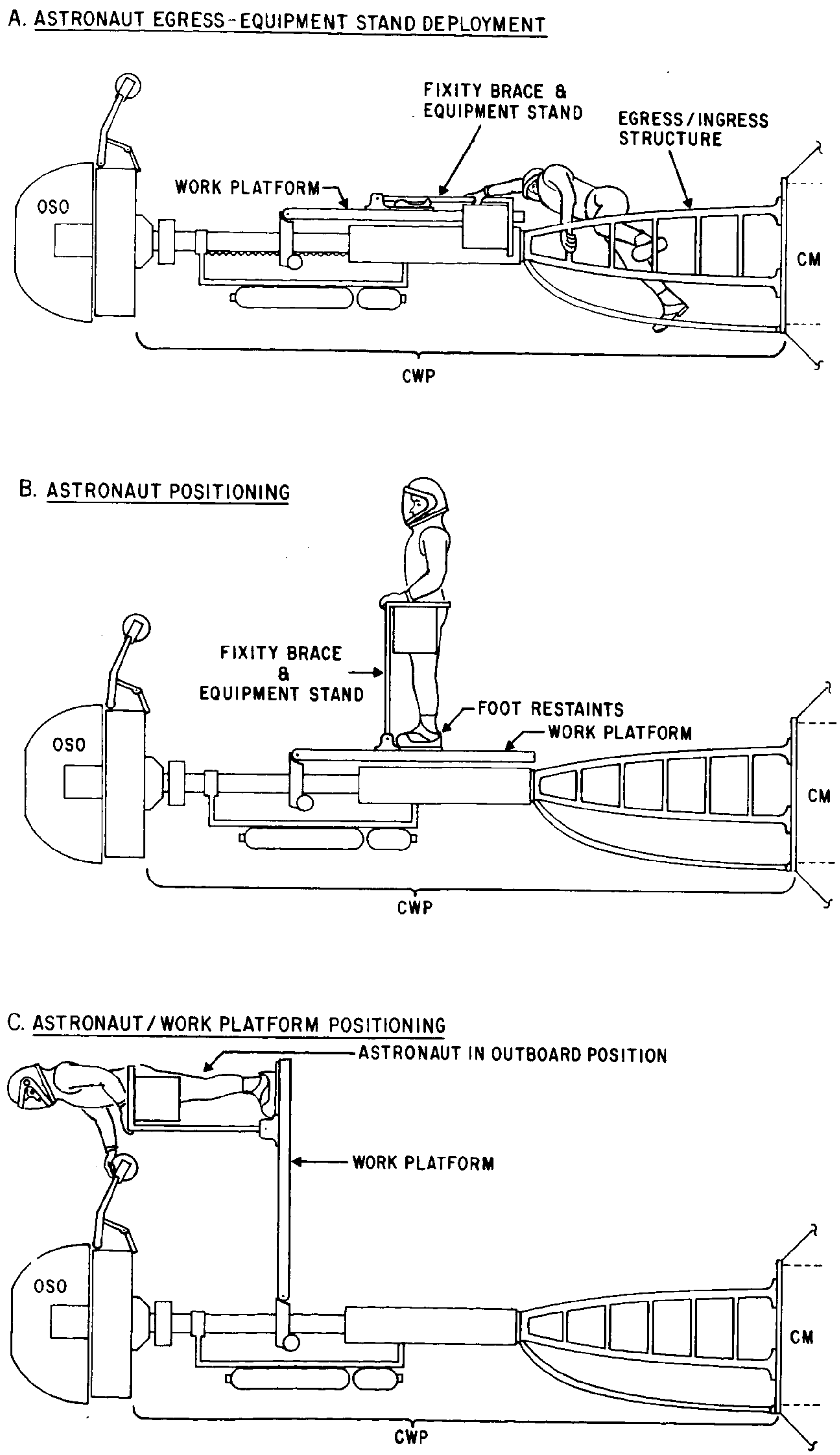

Fig. 5-2 Work Platform Erection Sequence

5.3.1 Prerequisite Inspection

Inspection tasks that are required to establish decisions to proceed with the operations, or to establish safety conditions are considered prerequisite to each mission. These tasks include: determination of OSO dynamics; determination of OSO radioactive levels; equalization of electrostatic potentials; and verification of OSO conditions. The problems studies in each of these areas are discussed in the following sections:

5.3.1.1 Determination of OSO Dynamics

The capture operation can only be performed if the OSO dynamics are within specified limits as discussed in Section 4. These limits are based on the spin rate of the OSO and its wobble about its spin axis. Should the spin rate be less than a minimum value, the initial contact with the OSO could conceivably cause it to tumble rather than to precess. Operationally, the capture head must be prespun to nominally match the OSO spin rate prior to contact.

As indicated in Section 4, the OSO spin rate should be well above the minimum for all possible OSO targets and the wobble should be less than the maximum limit. However, these dynamics should be verified prior to the decision to proceed with capture and to determine the desired spin rate for the capture head.

5.3.1.2 Determination of OSO Radioactive Levels

The OSO should be examined to determine that its residual level of radioactive is below common safety standards, before any decision to proceed with EVA operations. The in-orbit OSO's are bombarded by high energy particles and gamma rays during their lifetime and may consequently become slightly radioactive. The radioactive sources on-board the OSO are all relatively weak and are encapsulated; they therefore present no significant hazard to the astronaut. (Refer to Appendix A.) The radioactive flux from the target OSO should be measured prior to the decision to initiate EVA.

5.3.1.3 Equalization of Electrostatic Potential

An OSO that has been in orbit for any length of time may have accumulated a significant electrostatic potential. This potential must be neutralized with respect to the CSM and the EVA astronaut prior to any contact of the astronaut with the OSO. A discharge probe should be used to contact the OSO during the capture operation to equalize the charge. This probe should indicate to the crew that the charge has been equalized prior to the decision to initiate the EVA operation.

5.3.1.4 Verification of OSO Condition

The OSO should be examined during the circumnavigation phase to determine its general condition. Such examination can verify the condition of key parts of the OSO preparatory to the capture operation and to the useful work tasks. Significant items that should be checked include: (1) whether the arms are extended; (2) whether any scheduled experiment extentions are properly extended; and (3) whether any damage has occurred to the OSO. Determination of the OSO condition enables the crew to decide if they sould proceed with the work profile or if they should alter it for any changed or unexpected condition. This examination should be continued when the EVA astronaut is in close proximity to the OSO and throughout the useful work effort.

5.3.2 Documentation

Documentary inspection tasks should be performed to cover the capture operation and the EVA useful work tasks on each mission. These tasks primarily provide photographic coverage of the operations, but they should include voice annotation of the activities.

5.3.2.1 Capture Operation

Photographic coverage of the capture operation should be provided from within the CSM cabin. This coverage should include low frame rate motion pictures, which will verify the OSO dynamics as well as determine the relative motions between the CSM and the OSO throughout the operation. Such movies will document the ability of the crew to close properly with the OSO and will also document the detailed performance of the capture head as it contacts and contains the OSO. The movies should be continued until the despin operation has been completed.

5.3.2.2 Useful Work Activities

Documentary movies should be taken of the useful work activities to provide data on the erection of the work platform and on the performance of the detailed tasks. It is expected that the work platform will be erected automatically; thus the movies will document its performance; these can be taken from the CSM cabin. A low frame rate movie camera should be installed on the work platform to view the work being performed on the OSO. Such documentation will aid in improving EVA techniques and will provide higher magnification images of the OSO than those taken from the cabin. This operation and the conduct of useful work will require artificial illumination.

5.3.2.3 Release Operation

The release operation should be photographed to document the performance of the release system and the OSO dynamics following release. Movie coverage similar to that for the capture operation should be provided.

5.3.3 Investigation

A variety of inspection tasks to investigate specific areas of interest should be performed on each mission. These areas include: (1) radiation effects on external surfaces; (2) micrometeorite effects on external surfaces; (3) condition of moving parts; and (4) status of OSO configuration, including the scientific experiments. The investigative inspection tasks will vary from visual and photographic observations to manual manipulation of parts of the OSO or the experiments. Many of these items can be observed as other work tasks are being performed and thus will not require independent activity.

5.3.3.1 Radiation Effects on External Surfaces

The long term exposure of the external surfaces of OSO to the radiation environment may produce changes in the properties of the surface preparation. Each of the external surfaces of the OSO has a unique preparation to maintain the proper thermal balance for the various subsystems; thus, any changes will effect the long term thermal stability. Detailed color photographs should be made of selected external surfaces and compared with similar photographs taken prior to the OSO launch.

5.3.3.2 Micrometeorite Effects on External Surfaces

In addition to the radiation effects on external surfaces, it is expected that detailed photographs will reveal information on the micrometeorite effects. (See Section 5.4.1.3). It may be possible to obtain both the radiation and micrometeorite information from the same photographs. However, in the latter case, particular emphasis must be placed on high magnification and good prelaunch comparison photographs. Oblique lighting may be required to highlight the micrometeorite topography of the surface.

5.3.3.3 Condition of Moving Parts

The OSO has several moving parts that are externally accessible, which could be easily checked for changes due to the long term space operation. These include the bearing axes between the sail and the wheel and between the pointed experiments and the elevation frame, as well as a variety of spring loaded aperture covers and doors. Specific qualitative checks can be made of these movements during the EVA operations (e.g.) the manual rotation of one part with respect to the other.

It should be noted that the relative motion between the sail and the wheel can be observed during the despin operation, since the sail is free to rotate after capture until the bearing friction reduces its spin momentum. The movies of this operation can indicate the duration of this decay and can compare it with early orbital data to determine any change in performance.

Qualitative checks on the other moving parts by the EVA astronaut may reveal any extreme changes in the bearing condition or any major tendency for parts to cold weld. Such information gained on the first mission may have a significant effect on the tasks of the later missions, and successive comparisons of similar data may indicate any time variation in the effects.

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5.3.3.4 Status of OSO Condition

General inspection should be made of various parts of the OSO and its scientific experiments to verify proper operation of the mechanical parts or to determine their status. Visual observation and recorded voice annotation accompanied by selected photographs of objects of opportunity should be used. Particular emphasis should be placed on any damage or on parts that have had erratic or suspect operation. High magnification photography should be used to record the condition of experiment optics in order to verify or correct the data obtained during its operation.

5.4 MATERIAL RETRIEVAL

The retrieval of materials from an orbiting OSO provides an excellent opportunity to investigate the effects of the space environment on a variety of typical materials and mechanisms used in space hardware. Analysis of retrieved materials can provide data on the effects of radiation and micrometeorites on surfaces and materials, on the effects of prolonged exposure to high vacuum, and on the causes of instrumentation failures during orbital operation.

Retrieval from orbit is necessary to determine the integrated effect of the space environment, since ground simulation tests cannot adequately duplicate all of the conditions. Analysis of retrieved materials and mechanisms may lead to improved design of space hardware, particularly for increased duration missions.

The retrieval of malfunctioning or failed systems is the only method to determine completely the exact cause of the failure. Analysis of in-orbit failures can lead to improved design of space hardware and increased relaibility on future missions.

The evaluation of materials to be retrieved must account for the value of the analysis in terms of the expected results and the ease of removing and handling the material. Retrieval of most materials must be performed on an inactive OSO unless replacement parts are installed.

It will not be possible to retrieve all of the parts or samples desired, due to the inherent limitations of the EVA operations, the available mission time, and the CM return storage space and weight limitations. Therefore, it is essential that the retrieved parts serve as many of the aforementioned investigations as possible; there should be no excessive duplication. Review of the OSO II materials and mechanisms has revealed that retrieval of a relatively few major assemblies can provide data for each of the desired investigations.

Therefore, the recommended target OSO for the primary material retrieval mission is the OSO II, based on the expected high yield of useful information. Additional material retrieval tasks can be performed on the later missions. These should be restricted to nondestructive replacement since the major mission objectives are OSO refurbishment. Any parts or assemblies that are replaced as part of refurbishment should be returned to the surface for evaluation. Experiments may be planned for later OSO missions that include retrieval of specific materials.

5.4.1 Environmental Effects on Materials and Optics

The effects of the space environment on materials can best be determined by retrieval of specific materials from an OSO that has been in orbit for an extended period of time. The major effects that can be evaluated are those caused by the radiation and micrometeorite fluxes and those caused by prolonged exposure to high vacuum and low gravity. The probable effects have been evaluated for the major types of materials and optics used on an OSO.

5.4.1.1 Solar Cells

One of the most widely used spacecraft systems that should be analyzed is a solar cell array. All OSO satellites use solar cell arrays to provide power to the subsystems and experiments. This array consists of protective cover glass, solar cells, bonding agents, and a mounting substrate. Each of these materials should reveal the effects of space radiation, but the cover glass should show the major effect of both the ionizing and the micrometeorite fluxes. The solar cells may show a semiconductor degradation due to local changes in the crystal lattice. Determination of the nature of the degradation of solar arrays experienced on most satellites could lead to improved designs for future spacecraft.

5.4.1.2 Polymeric Materials

All spacecraft, including the OSO, use polymeric materials such as electronic components, epoxies, and surface preparations, all of which are somewhat effected by high vacuum and space radiation. The energy per photon in the near ultraviolet region exceeds the energy of typical polymer bonds; therefore, polymer breakdown is likely to occur in materials receiving direct radiation. Vacuum and temperature can affect the mode of change in polymers due to radiation. The rate of evaporation can change significantly by chain scission due to radiation producing fragments of much lower molecular weight than the parent material. Radiation of certain polymers can also cause cross-linking, which may result in large changes in mechanical and physical properties.

A large variety of polymeric materials is used on the OSO, and the retrieval tasks should provide significant amounts of the typical materials. Analysis of these retrieved materials should indicate the extent of change and whether any of the design features are compromised.

Scientists contacted during this study have indicated interest in obtaining a variety of polymeric materials to determine the integrated effect of the space environment.

Typical of the scientific value of retrieving polymeric materials is the expected results from retrieving the OSO II Ames Research Center Emissivity Experiment. Mr. C. Neel, the principal investigator for this experiment, has reported that ground analysis of the experiment sensors would add significantly to the value of his earlier data. Figure 5-3 presents the data obtained by telemetry for one of his sensors with the last data obtained in 1966, after 3,000 equivalent sun hours. The uncertainty in extrapolating these data is indicated by the cross-hatched area. If no further telemetry data becomes available, the expected change in the emissivity properties can not be verified. Data obtained upon retrieval of the sensors would determine their long term variation, such as whether the expected change in coating No. 8 does occur. The various sensors used on this experiment are samples of materials commonly used on satellites, and the long term data on each will aid in future spacecraft design.

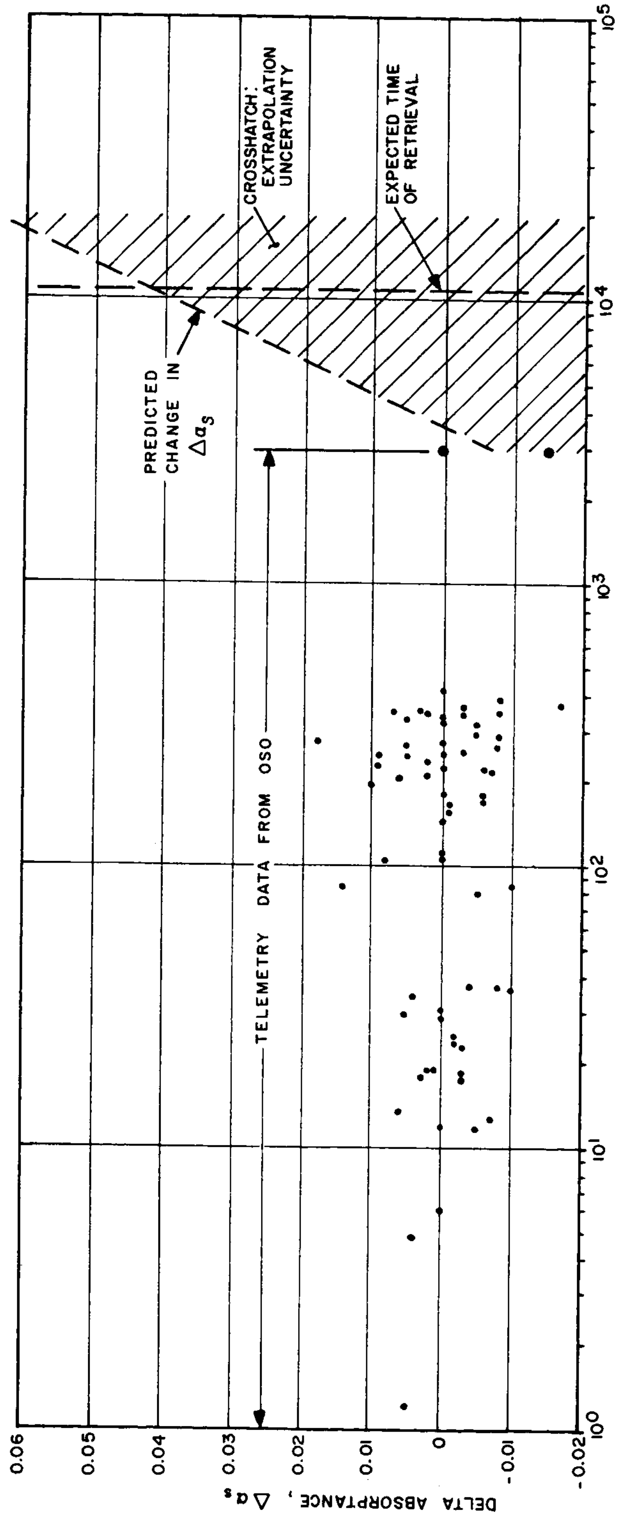

Fig. 5-3 Delta Solar Absorption

5.4.1.3 Metallic Materials

A variety of metallic materials are used on the exterior of the OSO satellite and experiments. The major space environment effect on metals is that of meteorite impact. Although the probability is low that the OSO will have sustained any damage from meteorites, the metallic surfaces should yield important new data on the fluxes of micrometeorites in the near-earth environment.

The available data on micrometeorite fluxes obtained by various means is shown in Fig. 5-4. Note that there is a significant range of particle mass from 10^{-5} to 10^{-8} grams for which there is no empirical data. Since the target OSO's for the material retrieval mission will have been in orbit for approximately 1.5 x 10^{-9} seconds, a minimum of one impact per square meter is expected for masses less than 10^{-6} grams. The gold plated aluminum covers over the exterior of the Harvard College Observatory experiment on OSO II include about 1 square meter of exposed surface. These covers were highly polished and thus should provide an excellent sample for determining the existence of impacts of particles. Therefore, examination of impact craters in the gold covers should reveal crater sizes proportioned to micrometeorite masses less than 10^{-6} grams; this includes the region where no data has been obtained.

Retrieval of metallic surfaces that can provide micrometeorite impact data from an OSO will extend the knowledge of the near-earth environment in an area that cannot easily be covered in any other way. Improved definition of the probable particle fluxes will aid in improved designs of high precision orbiting telescopes that can be used for many years.

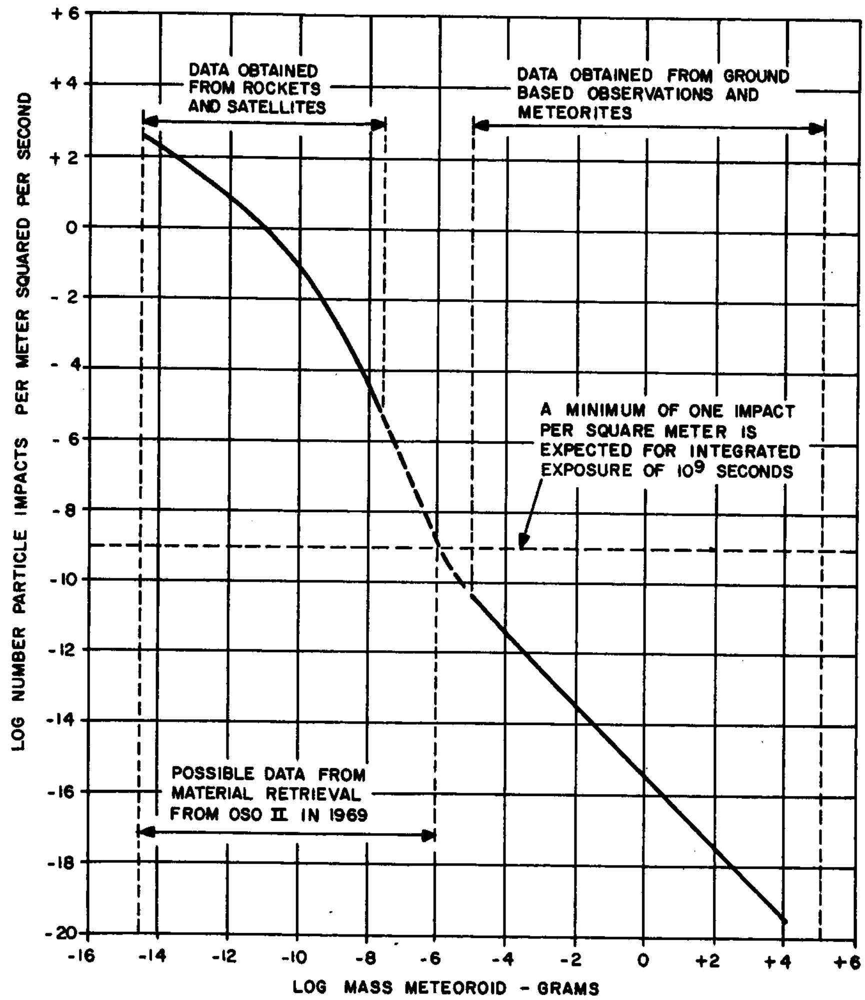

Fig. 5-4 Meterorite Flux

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5.4.1.4 Optics

Optical components perform essential functions on almost all spacecraft, and particularly on the OSO's. The pointing control sensors on OSO as well as the majority of the scientific experiments utilize precision optics. Adverse effects of the space environment can significantly alter the performance of the optical systems or the scientific results.

Specific environment effects that could be observed on optics after a prolonged exposure are as follows:

- Surface damage by micrometeorites and sputtering
- Browning or yellowing discolorations which decrease transmissivity as some function of wavelength
- Changes or acquisition of luminescence and fluorescence properties
- Shifts in index of refraction
- New or enhanced absorption bands
- Devitrification which crystallographically and physically alters glass structure, thereby rendering the glass nonhomogeneous and increasing absorptivity
- Contamination due to sputtering and outgassing of other materials on the spacecraft and photopolymerization of condensed films

Retrieval of lenses, filters, mirrors, cover plates, and grating can provide data on each of the above effects. Such data can aid in predicting or improving the operation of optical components in future space instrumentation.

5.4.2 Mechanisms

The design of mechanisms for spacecraft use has required the development of specialized lubrication techniques and bearing surfaces. Evaluation of the performance of such mechanisms on an OSO would be greatly enhanced by detailed inspection of the mechanisms after prolonged exposure or operation in the space environment.

Ground simulation cannot completely reproduce the integrated effect of the low gravity and high vacuum operation for a period of years on the mechanisms used. Mechanisms on OSO that would provide direct determination of the performance of alternate methods of design, include the bearings of the satellite as well as drive mechanisms within some of the scientific experiments. Retrieval of the satellite bearings would require extensive disassembly of the satellite; this is beyond the scope of these initial ESMRO missions. However, several mechanisms are reasonably accessible within the OSO II such as the HCO and GSFC ultraviolet (UV) experiments.

The HCO grating drive mechanism has a bearing surface of an aluminum shaft rotating in a teflon sleeve. The GSFC-UV azimuth indexer mechanism is a conventional bearing operating in one atmosphere of helium. Contrasting performance data obtained from these retrieved mechanisms, or others replaced on later missions, will greatly aid in the design of future mechanisms.

5.4.3 Failure Analysis

One of the most significant accomplishments that could be performed on the OSO II would be the diagnosis of some of the more significant failures that have occurred on the scientific experiments. The telemetry data available on the experiments that experienced problems (or failures) has not been extensive enough to determine the causes.

In one case, the failure of the experiment has not been adequately explained and may be a unique function of the operation of that type of instrumentation in the space environment. This is the case of the OSO II HCO high voltage failure at turn-on. Since many space telescope systems use similar high voltage and sensor systems, it is essential that this failure be extensively analyzed. Dr. L. Goldberg, the principal investigator for this experiment has stated that the most comprehensive analysis that can be made is on the actual instrument that failed. Direct examination for evidence of high voltage breakdown should yield the best diagnosis of the failure. Such examination can only be performed by retrieving the entire instrument, and then disassembling and examining it in a laboratory. Similar failures have occurred in the two NRL experiments on OSO II, but only after operation for several hundred orbits. It is expected that retrieval and analysis of the HCO experiment should provide sufficient data to diagnose the NRL failures.

Erratic stepping sequences were observed on the GSFC—ultraviolet spectrophotometer azimuth indexer during orbital operation. The problem seemed to be aggravated by passage through the South Atlantic magnetic anamoly. This mechanism is reasonably accessible, and its retrieval would enable diagnosis of the erratic operation. Successful diagnosis would aid design of future instrumentation to avoid a similar problem.

Other failure or malfunctions that have occurred on OSO II equipment involve mechanisms or electronics that are relatively inaccessible and therefore are beyond the scope of these initial ESMRO missions.

5.4.4 Handling

The materials retrieved from OSO must have special handling in order to preserve the state of the effects of the space environment. This special handling must begin during the retrieval operation and must protect the materials in the CSM in orbit and throughout the recovery of the crew and CSM. This kind of care must be maintained until the laboratory investigations are complete. The handling requirements differ for each type of material; they are discussed in the following paragraphs.

5.4.4.1 Solar Cells

Retrieved solar cell panels should be handled in a manner that does not change the degradation effects. Since these effects are largely semiconductor and adhesive degradation and micrometeorite damage to the cover plates, the retrieved panels can be stored in an inert gas at a temperature less than 60°C. The storage container should maintain this environment until it can be opened in a clean room environment for investigation.

5.4.4.2 Polymeric Materials

The variety of polymeric materials that may be retrieved could require different handling procedures, depending on the type of investigation. Samples that may exhibit surface contamination should be stored in a clean container at the orbital vacuum pressure. This avoids any reaction with gas contaminants and requires that the sample be opened and inspected in a vacuum chamber. As with other materials, the storage temperature should not exceed room temperature or further changes may occur. Any atmosphere leaking into the vacuum container should be an inert gas to minimize chemical reactions.

Other polymeric materials that might be analyzed for gross property changes, such as the Ames Research Center Emissivity sensors, should be stored in an inert gas in a protective container. The container should be opened in a clean room for investigation. During the retrieval operations, a cover plate should be secured over the sensors to protect them from contact.

5.4.4.3 Metallic Materials

Retrieved metallic materials should be stored in an inert gas to avoid any changes in the surface appearance. The handling and storage container should minimize contact so as to avoid scratching or damaging the surfaces to be inspected for micrometeorite impacts. The samples should be opened in a clean room for inspection.

5.4.4.4. Optics

Some of the main objectives in recovering optical components is to determine their surface condition. In general, retrieved optics must be stored in a sealed vacuum container to avoid atmospheric changes to the surfaces. Any atmosphere that may leak into the container should be an inert gas to minimize chemical reactions. The retrieved samples should be stored so that they do not exceed room temperature. Initial inspection should be performed in a vacuum chamber. The optics should be covered during the retrieval operation to avoid direct impingement of oxygen from the astronauts suit or from the CSM RCS thrusters.

5.4.4.5 Mechanisms

Retrieved mechanisms should be stored in an inert gas environment and should not exceed room temperature. They should be opened in a clean room environment for inspection.

5.4.4.6 Failure Analyses Parts

Parts that have been retrieved for failure analysis should be stored in an inert gas environment and should not exceed room temperature. They should be opened in a clean room environment for inspection.

5.4.5 Post-Flight Analysis

The post-flight analysis techniques differ for each material investigation. The general requirements have been studied for each material investigation and are discussed in the following paragraphs.

5.4.5.1 Solar Cells

The primary method of evaluating the affect of the space environment on solar cells is to measure the changes in operational performance. The solar array is to be calibrated in the same manner as it was prior to launch, and the data will be compared. Discrete calibration steps should be made to progressively determine the degradation due to changes in the cover plates or the adhesive versus changes in the solar cells.

The cover plates should be examined spectrographically for evidence of contamination, and microscopically for micrometeorite impacts. As an optical component, they should be examined for changes in transmission characteristics. The solar cells should also be examined by X-ray techniques to evaluate changes in the crystal lattice structure.

5.4.5.2 Polymeric Materials

The analysis of polymeric materials varies depending on the specific materials retrieved, and the objectives of the investigation. Minor variations in polymeric materials can cause gross changes in certain properties. Radiation does not have similar effects on all properties. Evaluation of the retrieved samples should be compared with similar evaluation of prelaunch samples from the same batch of material, and post-launch evaluation of duplicate samples retained in storage.

The following characteristics of retrieved polymeric materials should be evaluated to determine the affects of the space environment:

- Rate of weight loss in vacuum
- Chemical analyses by infrared techniques on the bulk material and condensed films
- Mass spectrography on the bulk material, condensed films, and the outgassing species in vacuum

- Absorptivity and emissivity of thermal control surfaces
- Mechanical and physical properties

The post-flight analysis effort should be conducted in a material and processes laboratory that is equipped to open the containers and perform the initial measurements in a vacuum facility. The Ames Research Center emissivity sensor should be evaluated by Mr. O. Neel, the principal investigator on that experiment, who will perform post-flight calibration of each of the sensors in the same manner as his preflight calibrations.

5.4.5.3 Metallic Materials

The primary analysis to be performed on retrieved metallic materials is the examination for micrometeorite impacts. This evaluation should be performed in a laboratory properly equipped for visual examination of the surface topography over a range of magnifications. Comparisons should be made with the topographic features determined prior to launch; this should provide the most information on mass and velocity distributions.

5.4.5.4 Optics

The post-flight analysis of optical components should be performed in the laboratories that performed the prelaunch calibration of the components. The general character of the changes can be determined by evaluation of the reflection, refraction, transmission, and interference properties. More detailed analyses can be performed by high magnification topographic studies and X-ray analysis of the internal structure. Infrared and mass spectrography techniques would be applicable for identification of surface contaminants.

5.4.5.5 Mechanisms

Retrieved mechanisms should be returned to the laboratory that developed them for mechanical and operational tests. The post-flight evaluation can be compared with data obtained prior to launch.

5.4.5.6 Failure Analysis

Parts retrieved for failure analysis should be returned to the laboratory that developed them for diagnostic test. The diagnosis should be based on visual and mechanical appearance and functional operation or dissection following the same techniques used during the prelaunch testing.

5.5 REFURBISHMENT

Two of the three ESMRO missions studied are to have primary emphasis on performing refurbishment of the OSO satellite. The objective of the refurbishment effort is not only to refurbish an OSO, but also to develop EVA tasks that progressively increase in complexity. The combination of these two goals has been studied in order to determine the specific tasks to be performed.

The goal of refurbishing an OSO has led to an evaluation of what will be required to be refurbished on OSO's in the 1969 to 1971 time frame. Three classes of orbiting OSO's have been defined: (1) an OSO that has completed its useful mission and the mission has been officially terminated; (2) an OSO that is under fabrication at the present time and is to be in orbit during this time period; and (3) an OSO that has not had a design freeze at the present time but which will be in orbit during this time period (this class could be significantly modified to facilitate refurbishment).

The first class of OSO's have not been considered since their refurbishment would not particularly advance their original scientific objectives. OSO's in the second classification have passed their design freeze dates and could not be significantly modified to facilitate refurbishment. However, their scientific mission could be extended to provide significant new data by refurbishment. The third class of OSO's could be modified to provide for more complex refurbishment consistent with the evolutionary goals. Similar to the OSO's in class 2, their scientific mission could be extended or improved by refurbishment.

The type of refurbishment that can be accomplished on the two missions is therefore somewhat dictated by the degree of modification that can be designed into the OSO. The general categories of in-orbit refurbishment include: (1) modification and replenishment, (2) calibration and adjustment, and (3) checkout. The evolutionary trend for refurbishment will be established by the increased emphasis in the third class to perform more complex functions in each of these areas.

The modification and replenishment functions that will improve the OSO performance or extend its useful life are: (1) replacement of expendables, (2) correction of degradation effects, (3) preventative or corrective maintenance, and (4) improvements. Refurbishment tasks in each of these functions have been studied in a manner consistent with the capability to modify the OSO design for the two missions. Each in orbit refurbishment category is discussed in the following sections.

5.5.1 Replacement of Expendables

The most significant limitation to the long term operation of an OSO is the consumption of expendables. Two subsystems utilize expendables that are used systematically throughout the orbital operation. These are: (1) the pitch control gas supply, and (2) the spin control gas supply. In addition, the scientific experiments may utilize expendable features. Refurbishment of an OSO should include replenishing these supplies as discussed in the following paragraphs.

5.5.1.1 Pitch Control Gas Supply

The OSO pitch control subsystem maintains the pitch attitude of the OSO so that the pointed experiments are aligned within ±3 degrees (the limits of the elevation gimbal) of the solar direction. It utilizes the reaction thrust of cold gas through nozzles located in the sail structure. Pitch corrections are automatically made when the orientation exceeds the elevation gimbal limits.

The pitch gas supply budget is planned to exceed the six months design life of the OSO. However, to extend its useful life significantly may require replenishing the pitch gas supply. This is illustrated by the pitch gas expenditure of OSO II (Fig. 5-5) as compared with expected rate based on OSO I performance. OSO II has apparently interacted with the earth's magnetic field differently than has the OSO I; this has caused the aforementioned relatively rapid expenditure of pitch gas. Since this magnetic interaction can not be completely predicted prior to launch, and since improved magnetic control features may not alleviate the problem, the replenishment of the pitch control gas supply is required to extend the life of an OSO.

Replenishment of the pitch control gas supply can be accomplished by attaching a new gas reservoir to the external fitting near the outer extremity of the sail structure, or by recharging the existing reservoir.

5.5.1.2 Spin Control Gas Supply

The OSO spin control subsystem maintains the spin rate of the OSO within a nominal operating range. It utilizes the reaction thrust of cold gas through nozzles located on each of the three arms. Spin corrections are automatically made when the rate falls outside of the nominal operating range.

The spin gas supply budget is planned to exceed the six months design life of the OSO. However, unknown orbital conditions, such as increased interaction between the OSO and the earth's magnetic field, may cause an excessive expenditure of spin gas. Therefore, in order to assure an extended operational life for OSO, its spin gas supply should be replenished.

Replenishment of the spin control gas supply can be accomplished by attaching a new gas reservoir to the external fitting on a wheel rim panel section, or by recharging the existing reservoir.

5.5.1.3 Experiment Gas Supplies

The scientific experiments assigned to an OSO may incorporate expendable gas supplies in the instrument to facilitate operational requirements. The NRL X-ray telescope experiment on OSO II which used a specialized quenching gas that flowed through the detector system and was expended overboard is typical. Similar designs on future OSO missions could benefit greatly by a replenishment procedure to extend the lifetime of the experiment.

5.5.2 Correction of Degradation Effects

Additional major limitations to the long term operation of an OSO are the degradation of subsystems due to expected affects of the space environment. Known degradation effects include: (1) decreased power output from the solar array; (2) decreased storage capacity of the power supply batteries; (3) decreased electromechanical performance from the tape recorders due to excessive operation; and (4) decreased experiment optical or sensor sensitivity.

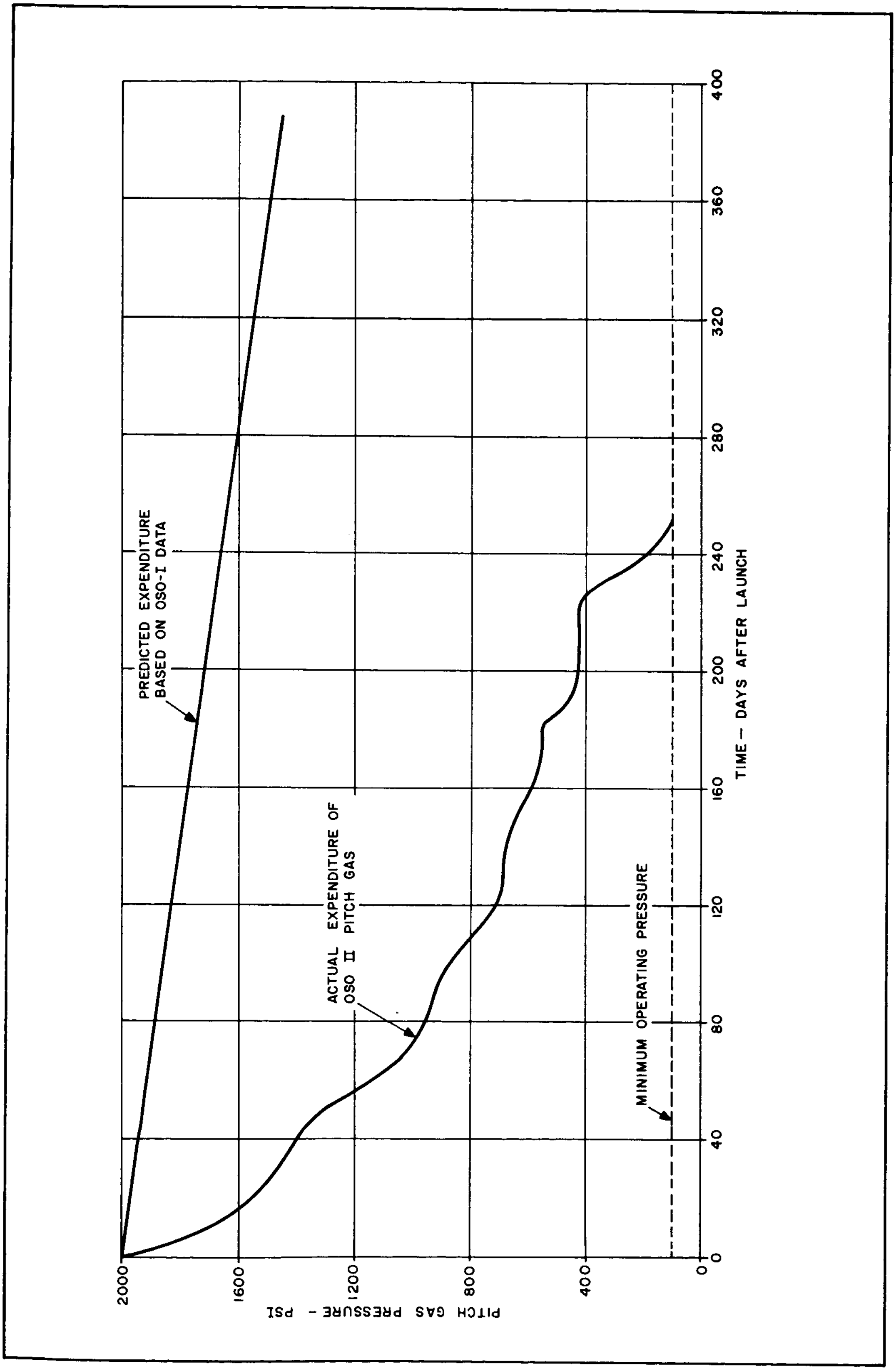


Fig. 5-5 OSO Pitch Gas Expenditure

5.5.2.1 Solar Array

The generation of electrical power by the solar array cells is a critical function of the OSO power supply, as it is on most long term satellites. The output of solar cells is known to degrade as a function of exposure to the space radiation environment. The power utilization budget for OSO is based on this expected solar array output, and is subscribed prior to launch to the level of full operation at six months, as shown in Fig. 5-6.

It can be seen that full operation of the OSO is not possible after six months and that duty cycling of the scientific experiments is required. This, of course, reduces the scientific value of the OSO after six months operation. Refurbishment of the OSO solar array would return the OSO to full operating capability.

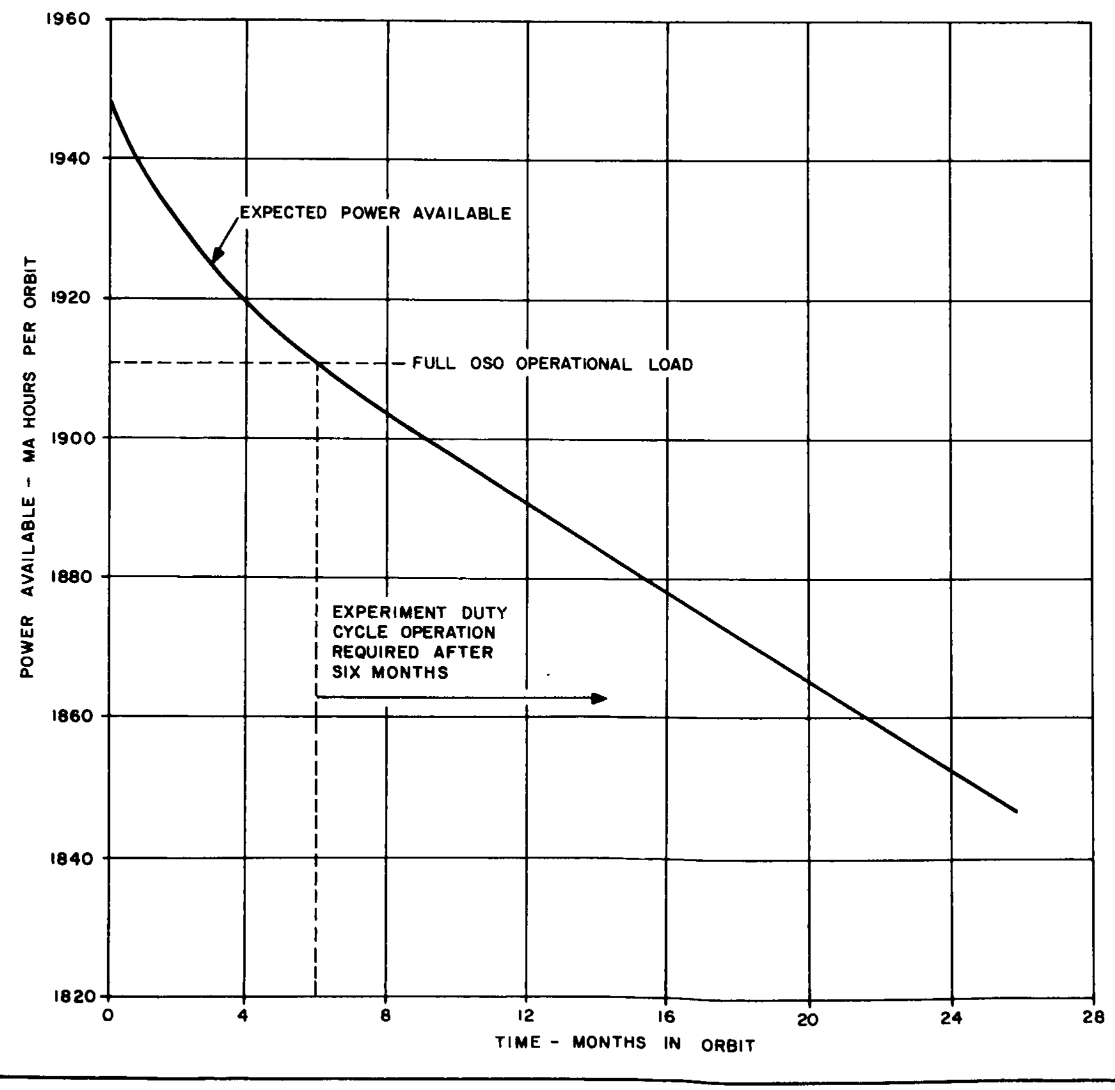


Fig. 5-6 OSO Power Availability Profile

Replacement of the original solar array with a new array is too comprehensive a task. Therefore, it is recommended that the new array be added either in parallel or in place of the original array. This can be accomplished by attaching the new array either to the sail structure or to the top of the original array. The electrical connection is made through an accessible connector on the sail junction box, and the new array can be connected through the same connector.

5.5.2.2 Power Supply Batteries

The OSO batteries provide power for both the orbital night time operations and peak loads. The storage capacity of these batteries is known to degrade with continuous orbital operation; the result is that the system voltage cannot be maintained at the necessary operating level. This automatically turns off the scientific experiments until the batteries are recharged. The charge/discharge cycle continues until the batteries can no longer sustain a charge. Refurbishment of the battery system would return the OSO to full operating capability.

The battery packs are contained in three of the nine wheel compartments and are relatively inaccessible for refurbishment. Therefore, it is recommended that new batteries be added externally to the wheel and connected into the system through the umbilical connector shown in Fig. 5-7. These could be added to specialized brackets that would attach to the wheel lifting brackets, shown in Fig. 5-8. Modification to later OSO's could be made to connect the batteries into the system locally at their mounting location.

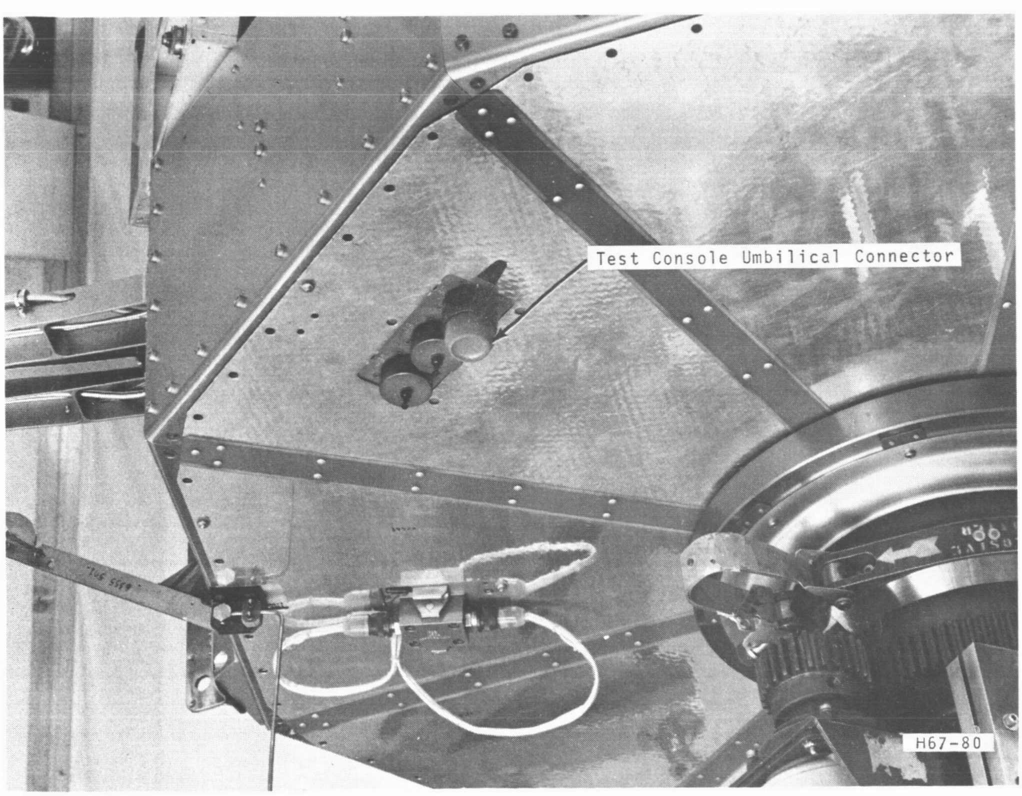


Fig. 5-7 OSO Umbilical Connectors (Flight Condition)

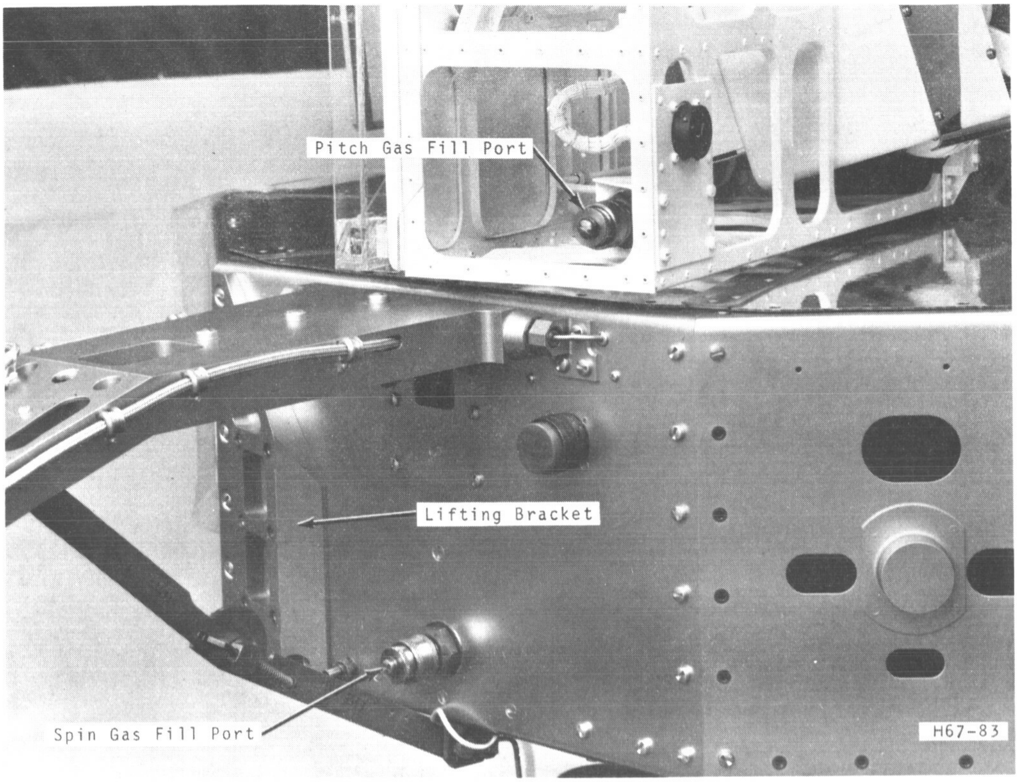


Fig. 5-8 OSO Gas Fill Ports & Lifting Bracket

5.5.2.3 Tape Recorders

The two tape recorders used on OSO are in continuous operation throughout the orbital lifetime. They have a continuous loop of tape that is controlled to record data at one speed and to playback data at a higher speed once each orbit. This electromechanical system has revealed some evidence of degradation in performance on OSO II, and failed after about 1000 orbits on OSO I. Since it can be assumed that later OSO's may encounter some tape recorder degradation, their refurbishment should be scheduled.

The tape recorder units are located in one of the wheel compartments and are relatively inaccessible for refurbishment. However, new tape recorders could be installed on exterior mounting brackets and connected into the system through the umbilical connector on the bottom of the OSO. Later OSO's could be modified to connect the tape recorders into the system locally at their mounting locations.

5.5.2.4 Experiment Sensitivity

Many of the OSO scientific experiments utilize optics or detectors that inevitably degrade with continued exposure to the sun's radiation. Changes in the transmission characteristics of optical elements or in the cathode efficiency of detectors are known to occur after long term operation. Refurbishment of such elements would enhance the extended operation of the affected experiment and improve the scientific yield of the mission.

The primary experiments that may experience such degradation are the pointed experiments located in the sail structure. Refurbishment of optics or detectors could be accomplished by replacement of the old elements with new ones. Access to these elements near the front or rear of the instrument could be made through access ports in the side or top of the instrument case. This type of replacement should be performed only on experiments designed for easy removal and installation of the new elements.

5.5.3 Preventative or Corrective Maintenance

Refurbishment should be planned for each mission in the areas of preventative or corrective maintenance. However, it is impossible to predict at the time of this study what maintenance will be required on an OSO in the 1969-1971 time frame. Furthermore, only limited maintenance could be performed on the OSO unless specific design modifications had been made to facilitate EVA maintenance. Analysis of each of the OSO subsystems in terms of reliability and criticality factors has revealed several areas that can be used as models for potential in-orbit maintenance (Ref. 10). These are discussed in the following paragraphs.

5.5.3.1 Pointing Control Subsystem

Any failure in the OSO pointing control subsystem could significantly affect the mission, since the primary experiments and the solar array rely on sun pointing. Loss of pointing would result in a complete shutdown of the mission since there would be insufficient power to operate the scientific experiments. Maintenance of this subsystem could be performed relatively easily, since the sun sensors and the electronics are externally accessible.

Replacement of the sun sensors could be made within the alignment precision required for the planned OSO missions. Replacement of electronics could be enhanced by specific design of the covers and printed circuit boards for easy EVA handling. The location of the two pointing control electronic units is accessible on the rear of the sail structure.

5.5.3.2 Spin Control Subsystem

This subsystem consists of sun sensors, electronics and the gas system, all of which are located in the wheel. The units of this subsystem are relatively inaccessable, and specific design modifications to the OSO would be required for EVA maintenance. Replenishment of the gas supply is discussed in Section 5.5.1.2.

5.5.3.3 Pitch Control Subsystem

The pitch control sun sensors are located on the top of the sail, and the electronics are located in the same boxes as the pointing control electronics. Therefore, maintenance of this subsystem could be performed in a manner similar to the maintenance on the pointing control subsystem.

5.5.3.4 Data Handling Subsystem

The data handling subsystem consists of a variety of electronics for handling, commutating, multiplexing, recording and transmitting the observatory data. The majority of the units of this subsystem are contained within the wheel compartments, and are relatively inaccessible. However, maintenance should be planned for this subsystem since it contains a large number of components, and since some failure modes could cause a significant loss of data and require the mission shut-down.

Due to the inaccessibility of the data handling subsystem units, any maintenance should be completed by the addition of new electronics on the exterior of the wheel, similar to that method discussed for the tape recorders in Section 5.5.2.3. Connection of new electronics to the system could be made through the umbilical or into specially designed connectors in the vicinity of the mounting brackets. Additional wiring modifications should be made to the OSO in order to facilitate the replacement of any of the major data handling units.

Maintenance of any part of the transmitting system would be relatively difficult, since addition of units would require exact impedance matching, and since the change in cabling may have a significant affect on the system performance. One exception to this is the portion of the antenna that protrude below each of the three arms in the form of stub dipoles. A new dipole could easily be replaced for one that had been damaged during capture; this would not adversly effect performance.

5.5.3.5 Command Subsystem

The units of the command subsystem are located in the wheel compartments, with the exception of the sail decoder which is mounted to one of the pointed experiments. New receivers would be difficult to add because of the handling of the RF matching and cabling; however, the wheel decoders would be replaced by adding new ones externally. The sail decoder would be easily replaced since it is accessible for removal.

5.5.3.6 Launch Sequence Functions

Several critical functions are activated by the launch sequence timer; should these fail to operate, the mission could be seriously jeopardized. These include: release of the arms from their launch position; release of the pointed experiments in the elevation frame; release of the nutation damper; and activation of experiment functions. Most of these functions involve the firing of an explosive device to release retainer pins.

In the case of failure of any of these mechanisms due to a failure of the launch sequence timer, corrective action could be taken. An auxiliary power supply could be plugged into the accessible squib circuits. Firing of the squibs presents no danger to the EVA astronaut, since their detonation forces are contained in a pressure cartridge. Manual operation of the pins would be possible in some cases if activating the squib circuits does not release the pin.

5.5.3.7 Power Subsystem

Maintenance of the power subsystem has been determined (Section 5.5.2) essential to the long term operation of the OSO.

5.5.3.8 Scientific Experiments

Maintenance of the scientific experiments on OSO is limited by the accessibility of the instrumentation or the specific EVA design features that can be provided. Since the specific scientific instrument to be worked on is not determined during this study, only general maintenance tasks can be discussed. Among these is corrective action on any external mechanisms (such as aperture covers or extendable booms) that fail to operate. Maintenance on electronics or internal mechanisms would require specific design to permit access or to add units on the exterior.

5.6 IMPROVEMENTS

Refurbishment of subsystems or experiments on the OSO to improve their performance could add greatly to the scientific yield of the mission. A valuable improvement that could be performed on the OSO in orbit is the addition of magnets or coils to correct for adverse interaction with the earth's field. The scientific experiments could also be adjusted, or modified, to improve their performance. These areas are discussed in the following sections.

5.6.1 Addition of Magnets or Coils

The excessive expenditure rate of pitch control gas on OSO II was due to the interaction of the OSO with the earth's magnetic field. This interaction could not be predicted prior to launch since it is apparently an induced dipole moment in some of the scientific experiment hardware. It is anticipated that on future OSO's this problem will increasingly reoccur. Corrective measures have been designed into the later OSO's, but since the magnitude of the effect can not be predicted, it is difficult to optimize these designs.

The effective direction of the induced dipole moment can be determined by analysis of the orbital data over a period of several months. Therefore, if the prelaunch design features of the OSO cannot completely correct this effect, the addition of other permanent magnets or bias coils would better compensate for the interaction. This would result in less use of the pitch control gas supply and extend the useful life of the OSO.

The magnets or coils could be added on the sail structure by means of simple brackets. The coils could be connected to a specially designed connector on the sail junction box in order to obtain the power and command signals necessary for their operation. Commands to operate the added coils could be reserved for this function on the later OSO's.

5.6.2 Experiment Modification

The OSO scientific experiments are designed to investigate unknown solar and celestial phenomena. Instrument sensitivity is established by the cognizant scientist during the development phases and is based on the best data or theories available at the time. Once the experiment has been operating in orbit for some time, the scientist may discover that the measurements are significantly different from what was expected, and that better data could be obtained if the instrument characteristics could be changed.

Such changes can be partially anticipated before launch and command functions designed into the instrument. However, many desired changes cannot be programmed into the command control of the instrument that could be accomplished by direct in-orbit modification such as threshold changes in the detector system. Refurbishment tasks should be planned to provide such improvement in the operation of the OSO scientific experiments.

5.7 CALIBRATION, ALIGNMENT, CHECKOUT

Associated with most of the refurbishment tasks are more specialized activities involving calibration, alignment, or checkout of the modified subsystems or experiment. Many of the evolutionary aspects of the second refurbishment mission could involve increased complexity in test areas. This is discussed in the following paragraphs.

5.7.1 Calibration

In general, replaced or new parts on the OSO are adequately calibrated during their development. However, modifications to the scientific experiments may require in-orbit calibration to determine the new instrument characteristics. For the experiment modifications anticipated for the early refurbishment missions, only minor calibrations may be required. However, later missions may require more extensive calibrations.

Included in the minor calibration category is application of known stimulus to experiment apertures. Stimulus application includes the natural radiation of the sun and specific radiation from a radioactive source. To calibrate an experiment with the sun, the experiment optical axis would be aligned to the sun by orienting the OSO/CSM configuration and by manually aligning the experiment, or by activating the OSO to point at the sun. Repeated calibrations could be made following separate adjustments of the experiment until sufficient data have been accumulated by means of the OSO telemetry system or onboard the CSM. Radioactive calibration sources could be temporarily mounted to an experiment aperture to provide a known stimulus. A series of calibration points could be examined by means of the OSO telemetry or on-board the CSM.

Some calibration techniques will require positioning of the OSO/CSM configuration only, while normal telemetry data are recorded. Typical of these is the calibration of the roll aspect magnetometer following the installation of new permanent magnets. These magnets introduce an error into the measured data, resulting in erroneous determination of the absolute roll angle of the OSO. One procedure for calibrating this error would be to measure the roll angle before and after the installation of the magnets but with the CSM and OSO in the captured configuration. This would be accomplished by measuring both the OSO data and the CSM inertial reference by telemetry and then calculating the roll angle from both sets of data. The data obtained following the magnet installation should reveal any error resulting in the magnetometer data output.

5.7.2 Alignment

Alignment of optical axes will become a major requirement for the future in-orbit assembly of major telescope systems. In order to provide basic information leading to this capability, minor alignment tasks should be scheduled for early missions. Typical of minor alignment tasks that could be accomplished are those involving replacement of experiment optical elements or detectors.

If these elements cannot be designed to mechanically register to the alignment precision required, then adjustment mechanisms could be designed into them. These adjustments could be two dimensional movement of the new element with respect to a reference surface. Activation of the adjustment could be made by a special purpose tool installed in the instrument and manipulated by the EVA astronaut. Telemetry data or data presentation in the CSM could be used to assist the EVA astronaut in the alignment operation.

5.7.3 Checkout

Checkout of each subsystem or experiment that has been refurbished should be performed. This checkout should consist of simple functional checks to verify that the operating status is proper. Similarly, checkout of the OSO should be performed prior to release to verify that it is operating correctly.

Checkout of the OSO can be performed by OSO ground stations that can command OSO functions and process and analyze the data. However, this would restrict this operation to orbits that place the OSO/CSM over the ground station. The relatively short real time coverage available would not allow enough time to analyze or completely checkout the OSO. Therefore, it is recommended that the in-orbit checkout be performed by using the CSM on-board checkout system (OCS).

This system has been evaluated and is compatible with the OSO data signals. Therefore, the OSO data signal could be delivered to the OCS by hard line through an umbilical which is connected when the CSM docks with the CWP. Checkout programs could be used to verify the proper operation of the OSO. The checkout functions could be performed in parallel with other EVA activity, unless the checkout function requires external stimulus or activation by the astronaut.

Commanding the OSO from the CSM could be accomplished by hard line if the OSO was modified to accept command signals from two sources. An alternate approach would be to transmit the commands from the CSM to OSO, which would require the installation of a command transmitter and necessary controls. The transmitter could be located on the CWP, with the controls located in the CSM cabin for operation by the astronaut conducting the checkout.

5.8 EXTRA VEHICULAR ACTIVITY

One of the major goals of the ESMRO missions is to advance EVA technology. The work effort that has been described in the preceeding Sections, is primarily to be performed under EVA conditions. The extent of this work effort varies widely and increases in complexity in the later of the series of missions. Even though the ESMRO missions are to provide the next major step in developing EVA technology, much has been learned from the Gemini program and other NASA studies that can be applied to the study of the ESMRO mission requirements. The major areas of EVA operations for the ESMRO missions that have been studied are: (1) astronaut stabilization, (2) tools, (3) support equipment, and (4) timeline analysis. These areas are discussed in the following sections along with the general considerations effecting EVA operations.

5.8.1 General Considerations

The general considerations of the EVA operations on the ESMRO missions are the restrictions involved in performing useful work. Several of these are discussed in the following sections.

5.8.1.1 CSM Egress/Ingress

All EVA operations start with the astronaut preparing for the EVA work by donning an outer garment, changing to an external life support system, and leaving the Command Module. Two methods of exiting from the CM are possible: (1) through the side access hatch, or (2) through the forward hatch (CM/LEM tunnel). Use of the CM/LEM tunnel for ingress and egress for the ESMRO missions is recommended, since the tunnel is designed for astronaut passage. Use of this exit will be required for several round trips, and it should have a higher reliability for repeated use than the side access hatch. Furthermore, current planning provides for the side access hatch to be used only for emergency exiting during a mission abort and for post earth landing egress.

Provisions for ingress and egress are shown in the CWP concept in Figs. 4-23 and 5-2. The lattice structure between the CM/CWP docking collar and the CWP boom permits the EVA astronaut to exit easily from the CM tunnel. After exiting, the lattice structure serves as hand-holds while the astronaut activates the work platform. Additional hand-holds can be located on the CWP to assist the astronaut to and from the work platform.

5.8.1.2 Command Module Pressurization

The Command Module must be depressurized and repressurized for each EVA work session. The present CM configuration can support up to three such pressurization cycles during a 14 day mission. Additional pressurization cycles (5 to 8) would be possible, but they would reduce mission duration.

Planned configurations of future space stations may include resupply modules and airlocks the would permit a larger number of egress/ingress cycles. It is also feasible to provide an airlock on the CWP to eliminate the need to depressurize the entire Command Module.

5.8.1.3 Life Support Systems

One major problem of EVA operations is the life support for the EVA astronaut. His life support system must be capable of operation for work sessions of several hours for the ESMRO missions. Astronaut egress and ingress is not possible through the CM/LEM tunnel with a portable life support system (PLSS) in place because of the limited diameter (29.5 inches). Use of a PLSS would require donning after egress and using an umbilical until the PLSS was in operation.

This would be a relatively difficult operation and would reduce the amount of EVA time available for useful work. The alternative is a long umbilical that would sustain the astronaut at the distance of the OSO. Umbilicals longer than the presently developed models which extend about 10 feet are being considered and should be developed at the time frame of the ESMRO missions. Therefore, it is expected that the life support system to be used for the ESMRO missions will be an umbilical, backed up by an emergency system on the astronaut that will fit through the egress tunnel. A further advantage of an umbilical life support system is that EVA work sessions can be planned for durations to fit the work load, other than restricting them to the operational duration of a PLSS.

5.8.1.4 Work-Rest Duty Cycle

The results of the Gemini program have shown that the EVA work load can easily fatigue the astronaut, and that periodic rest is required. On the rather long ESMRO EVA work sessions, proper work-rest cycles will be required to perform the experiment tasks. Periodic rest periods have been scheduled in the timelines prepared for these missions (See Section 5.8.5), but major emphasis has been placed on providing stabilization for the astronaut by means of the work platform.

5.8.2 Astronaut Stabilization

Stabilization of the EVA astronaut has been shown to be one of the most significant factors contributing to the ease of performing useful work under EVA conditions. Major Aldrin's experiences on Gemini XII have shown that either waist restraints or foot restraints provide good stabilization and enable the astronaut to use both hands for work. Aldrin was able to maintain his heart rate at a nominal working level, and to avoid any significant fatigue buildup while performing tasks similar to those required on the ESMRO missions.

Various methods of providing stabilization for the EVA astronaut have been evaluated as shown in Table 5-1. These include: (1) astronaut maneuvering unit (AMU); (2) hand held maneuvering units (HHMU); (3) tethers; (4) work platform. It can be seen from this table that the work platform has the best score.

The work platform discussed in Section 5.2 is to be used primarily for astronaut stabilization. The attachment of waist and/or foot restraints to this platform enables the EVA astronaut to fully utilize both hands for work up to the limit of his vision and mobility in the pressure suit.

Table 5-1
ASTRONAUT STABILIZATION TRADE-OFF CHART[a]

Criterion	AMU	HHMU	Tether	Work Platform
Foot restraints	0	0	0	1
Waist restraint	2	0	1	3
Astronaut reaction force capability	2	1	0	3
Automatic stabilization at work site	2	1	0	3
Rigid attachment to work site	0	0	0	1
Semirigid attachment to work site	0	0	1	0
No attachment to work site	1	1	0	0
Translation capability about OSO	3	2	1	1
Minimum energy expenditure for stabilization	2	1	0	3
Astronaut protected from OSO	0	0	0	1
Minimum astronaut encumberment	0	2	3	1
Astronaut in view of IVA astronaut at all times	2	1	0	3
Least contamination of OSO	0	0	1	1
Total:	14	9	7	21

(a) The largest number is most desirable

5.8.3 Tools

The material retrieval and refurbishment experiment tasks of the ESMRO missions involve several basic tasks: drilling, wrenching, cutting and prying. To accomplish these tasks within the mobility and dexterity constraints imposed by the EVA pressure suit, various tools are required. The tools can be of three different types:

- Power driven with a self-contained power drive
- Power driven with a universal power drive
- Hand operated

The number of individual tasks to be performed and the number of times that task is repeated influences the selection of the type of tool selected. Much development work has been done with zero reaction power tools but commercially available tools can be used if the astronaut is provided sufficient fixity. The ability to use commercial tools reduces the weight, size and power requirements, not to mention program costs. A minimum amount of modification is required for the utilization of standard hand tools for EVA operations. These modifications are directed mainly toward the gripping surface or handles to make them compatible with the pressurized glove, and, in the case of cutters, incorporation of a spring to maintain the cutting edges in an open position. A major consideration for hand-cutting tools is to minimize the hand motion necessary to operate the tool to approximately 1-1/2 inches. Ideally, the distance across the handles would be 3 inches while in the open position and 1-1/2 inches or more in the closed position. These dimensions are compatible with the gloved hand of the pressure suit. Provision for attachment of tethers must be incorporated in all tools, both to preclude their loss and to aid in stowage. The trade-off chart (Table 5-2) indicates the more desirable type of tools.

The specific tool requirements for each mission are given in Sections 6, 7, and 8.

5.8.4 Support Equipment

A variety of support equipment is required for the EVA operations of the ESMRO missions, such as cameras, lighting, tethers and containers. Most of this equipment will be stored or attached to the work platform in close proximity to the astronaut, to minimize the amount of energy used in handling tools and parts.

Table 5-2
EVA TOOL TRADE-OFF CHART[(a)]

Criterion	Power Drive With Interchangeable Attachments	Individual Power Driven Tools	Hand Operated Tools
Development required	0	1	2
Modifications of existing tools required	1	1	2
Multiple use	2	0	0
Minimum tool size and weight	2	0	1
Power requirement minimal	1	2	0
Minimal astronaut energy required for use	2	2	0
Astronaut fixity required for use	1	1	0
No tether required	1	0	0
Astronaut encumberment	2	0	1
Total:	12	7	6

(a) The largest number is most desirable

Containers designed specifically for each new or retrieved part greatly reduce the size and weight of the composite. They can also be designed as a composite container for a given type of protection of various parts removed from OSO. Containers to be returned for post mission analysis must be compatible with storage space allocations in the CM, such as the rock boxes or empty food compartments. An inert gas supply would be contained on the work platform for filling the containers.

The cameras required consist of still and motion types with various degrees of resolution and speeds. Motion recording cameras to be used for EVA documentation can be focused at a given area if the astronaut remains fixed. Still cameras are used for general area photography as well as high resolution photography. The use of a single camera with interchangeable lenses would reduce the amount of equipment to be stored on the work platform.

Tethers for use on tools, new or retrieved parts and other equipment are considered to be mandatory to preclude their loss. An object not at the center of gravity of the combined vehicles when removed tends to be accelerated away from the center of gravity until an energy balance is assumed and the object orbit established. Tethers attached to commonly used tools and equipment and a universal tether are recommended to save astronaut time. The tethers should have a windup reel attached to reduce the stowage problem and keep the astronaut from becoming entangled. The reel permits easy return and storage of the tether as the tool is placed in the tool box. Tools requiring the universal power drive for screw removal are stored in the tool box and are attached to the power tool before they are removed. For this reason, no tether is attached. The tools are also attached to the tool box on return before they can be released from the power tool. Tools required for specific operations on one experiment only are stored in the tool box and have no tether attached. The astronaut must attach the reel tether on the work platform to these tools before they are removed from the tool box and detach tether after they are returned to the tool box. This method of tethering limits the number of reels required while still keeping the number of operations required of the astronaut to a minimum.

Lighting of the work site is required for orbit day and night. The lack of an atmosphere to diffuse natural illumination produces the requirement for orbital day illumination. EVA documentary photography and selected object photography also require an illumination source. The area can be lighted by flood lights mounted on the work platform, and a mobile light can be used to provide selected illumination of objects in the shadow of the floods. A light can also be mounted on the power tool to aid in seeing the object being worked on.

5.8.5 EVA Time Line Analysis

The ESMRO mission plans presented in Sections 6, 7 and 8 include detailed time lines for the EVA and IVA effort. These time lines have been developed based on the detailed procedures for each experiment task. These tasks are planned to be performed by one EVA astronaut. Sequential operations could be performed by two astronauts, but this would require the training of two astronauts. If two astronauts were used in sequence the entire ESMRO mission profile could be shortened, since the time lines developed assume that one astronaut is working for three work sessions separated by at least 8 hours of rest in the CM. The work sessions include rest and orientation periods upon completion of each task in addition to rest periods included during the performance of the task. The frequency of the rest period included during the task performance are a function of both the accessibility to the work area, suit constraints, the working position, and the energy expenditure required for that particular task. The task times developed in the time line analysis are based on the actual time required to perform that task working on either an actual OSO satellite or simulated on a mockup. The times developed have been extended or adjusted to be consistent with experience gained during the Gemini flights.

5.9 RECOMMENDATIONS

The useful work phase of the ESMRO missions includes the major effort required to achieve the mission objectives. Successful completion of this effort depends on the techniques and equipment used. These have been discussed throughout this section and need only be summarized here.

The most advantageous technique for performing useful work on an OSO is to leave it attached to the capture mechanism on the nose of the CM. The EVA astronaut would egress through the CM/LEM tunnel and erect a work platform attached to the capture boom. He would attach himself to this work platform with waist restraints and/or foot restraints, and maneuver the platform up and down with respect to the OSO, or in an out between the arms. He would rotate the OSO to his position by releasing the capture spin mechanism. He would perform a variety of work tasks using conventional power tools with adaptive heads. He would work with periodic rest for a work session of several hours, followed by at least 8 hours of rest in the CM before the next work session.

A detailed description of each experiment task developed for the three missions is given in Sections 6, 7 and 8. These tasks are itemized in Tables 5-3, 5-4, and 5-5, and the category of each task is indicated. It can be seen that the technological and scientific achievement expected from each mission will greatly advance EVA technology and knowledge of the space environment, as well as extend the useful life of the OSO's serviced. The ESMRO mission concepts have been reviewed with several astronauts from the MSC Astronaut Office. Their comments can be summarized by Collins, who stated: "With this type of work platform facility, I should be able to perform the work tasks proposed."

Table 5-3
MISSION 1 EXPERIMENT TASKS

Task	Mission Support Operation	Environmental Effects on Material and Optics	Environmental Effects on Mechanisms	Failure Analysis	Replace Expend
Capture mechanism docking	X				
Rendezvous maneuvers	X				
Precapture inspection					
Determine OSO radioactive levels	X				
Determine OSO dynamics	X				
Documentation photography	X				
Capture operations					
Maneuvers and OSO containment	X				
Documentation photography	X				
Post-capture inspection and preparations					
Experiment preparations and radiation monitoring	X				
OSO centering	X				
OSO power bus removal	X				
Evaluation of mechanical freedom/damage			X		
Document observations and photography		X	X	X	

Table 5-3 (Cont.)

Task	Mission Support Operation	Environmental Effects on Material and Optics	Environmental Effects on Mechanisms	Failure Analysis	Replace Expend
Material Retrieval					
NRL corona graph occulting disk		X			
Pointing control sun sensor assembly		X			
Right hand solar panel		X			
HCO UV spectrometer		X	X	X	
Ames emissivity sensor plate		X			
U. of Minn. zodical telescopes		X			
GSFC UV azimuth indexer		X	X	X	
U. of N. Mex. telescope foil		X			
EVA document photography	X				
Container stowage preparation	X				
Refurbishment					
Replenish pitch gas					X
Return to CM and stow materials	X				
Release OSO and CWP jettison	X				
Post release inspection					
Determine OSO dynamics	X				
Documentation photography	X				

Table 5-4
MISSION 2 EXPERIMENT TASKS

Task	Mission Support Operation	Environ-mental Effects	Replace Expend	Correct Degrade Effects	Prevent or Correct Maintenance	Improve-ments
Capture mechanism docking	X					
Rendezvous maneuvers	X					
Precapture inspection						
Determine OSO radioactive levels	X					
Determine OSO dynamics	X					
Documentation photography	X					
Capture operations						
Maneuvers and OSO containment	X					
Documentation photography	X					
Post-capture inspection and preparation						
Experiment preparation and radiation monitoring	X					
OSO centering	X					
OSO power bus removal	X					
Evaluation of mechanical freedom/damage		X				
Document observation and photography		X				

Table 5-4 (Cont.)

Task	Mission Support Operation	Environ-mental Effects	Replace Expend	Correct Degrade Effects	Prevent or Correct Maintenance	Improve-ments
Material retrieval						
Refurbishment						
Replenish pitch gas			X			
Replenish spin gas			X			
Add battery supply			X			
Add solar panels				X		
Add tape recorders				X		
Maintain nutation damping lock					X	
Maintain arm lock					X	
Add stabilization magnets						X
Calibration of magnetometer						X
EVA document photography	X					
Return OSO to automatic operation	X					
Return to CM and stow materials	X					
Release OSO and jettison CWP	X					
Post release inspection						
Determine OSO dynamics	X					
Document photography	X					

Table 5-5

MISSION 3 EXPERIMENT TASKS

Task	Mission Support Operation	Environ-mental Effects	Replace Expend	Correct Degrade Effects	Prevent or Correct Maintenance	Improve-ments
Capture mechanism docking	X					
Rendezvous maneuvers	X					
Precapture inspection						
Determine OSO radioactive levels	X					
Determine OSO dynamics	X					
Documentation photography	X					
Capture operations						
Maneuvers and OSO containment	X					
Documentation photography	X					
Post-capture inspection and preparations						
Experiment preparation and radiation monitoring	X					
OSO centering	X					
OSO power bus removal	X					
Evaluation of mechanical freedom/damage		X				
Document observation and photography		X				

Table 5-5 (Cont.)

Task	Mission Support Operation	Environmental Effects	Replace Expend	Correct Degrade Effects	Prevent or Correct Maintenance	Improvements
Material retrieval						
Refurbishment						
Replenish pitch gas			X			
Replenish spin gas			X			
Add battery supply			X			
Add solar panels				X		
Add tape recorders				X		
Maintain nutation damping lock					X	
Maintain arm lock					X	
Add stabilization magnets						X
Add stabilizing torquing coils						X
Calibrate magnetometer						X
Replace pointing control electronics					X	X
Replace pointing control sensor				X	X	X
Replace experiment optics or sensor				X	X	X
EVA documentation photography	X					
Return OSO to automatic operation	X					
Return to CM and stow materials						
Release OSO and jettison CWP						
Post release inspection						
Determine OSO dynamics						
Documentation photography						

5.10 ASTRONAUT TRAINING

Each of the phases of the ESMRO missions must have an astronaut crew proficiently trained in the unique tasks required. The rendezvous phase will require training in the orbit transfer maneuvers, the visual acquisition of the OSO, and the station keeping maneuvers. The capture phase will require training, first to dock with the CWP and then to engage and capture the spinning OSO. This will require complete familiarization with the operation of the CWP and the dynamics of the two bodies at contact.

The most extensive training will be for performing the EVA work tasks. The EVA astronaut must be completely familiar with the operation of the work platform and the tools, as well as with the operations on the OSO.

The ESMRO training program should follow a sequential method of simulation in a one g "shirt-sleeve" environment, pressurized space suit environment at one g, and then neutral bouyancy simulation training and zero g aircraft flights in a pressurized suit. This type of program would thoroughly familiarize the astronauts with the operations, their sequence, the tools and equipment to be used, and with the performance of the experiment under simulated space conditions.

The available simulation facilities and techniques that would apply to an ESMRO training program are discussed in the following sections by the phase of the mission.

5.10.1 Rendezvous and Station Keeping

The orbit transfer phase of the ESMRO mission is similar to orbit maneuvers that have been performed during the Gemini program and that will be performed on the Apollo program. Therefore, the training required for the ESMRO mission is accomplished by the general mission training.

The terminal closure maneuvers, however, are somewhat unique and consequently require training with a rendezvous simulator that can vary the approach and visibility conditions similar to the possible ESMRO closure trajectories and visibility conditions. Practice maneuvering under all possible closure conditions should be performed.

Training for the station keeping phases should also be performed in a simulator that can display the OSO under the various lighting conditions expected. Both the night time maneuvering and day time circumnavigation should be practiced.

5.10.2 Capture and Release

The capture and release phases of the ESMRO mission present two docking and undocking maneuvers that will be similar to the docking and undocking of the CSM to the LEM. Training in the latter should provide a good background for the ESMRO mission requirements. The docking/undocking of the CSM to the CWP will be very similar to that of the CSM and LEM, since the CWP will have a LEM docking collar and will be stowed in the SLA.

The capture of the OSO with the CSM/CWP has several unique features, but in general is very similar to the docking of the Gemini spacecraft with the target Agena. The unique features are: (1) the CWP attachment head is to be spun-up to match approximately the OSO spin rate; and (2) the OSO is noncooperative but stable; that is, it will not automatically correct for or stabilize against the contact forces, but will precess if they are unsymmetrical.

The capture operation should be practiced in a facility that will simulate the various dynamic conditions and provide the crew with actual experience in handling the CWP and contacting the spinning OSO.

A simulator facility that would provide this type of training is that developed by the Martin Company in Denver, Colorado, and is described in Martin-Denver Research Report No. R-66-2. The simulator consists of a moving base that incorporates a six-degree-of-freedom carriage. The carriage is servo-driven in three translational axes and three rotational axes and is capable of carrying a 350 pound payload. The translational motions are longitudinal, lateral, and elevation. The carriage is supported on negator springs that counterbalance the weight of the elevation carriage and moveable head. The gimbaling system of the moveable head provides pitch, roll and yaw motions.

The target or mockup is mounted on a load cell array with the cells mounted in such a way as to continuously measure the three directional forces and moments generated by contact with the target. A computer uses the forces and moments from the load cell output to solve the equations of motion and generates position control commands to the servo-controlled base and moveable head. These commands provide resultant system motion to reactions from contact with or movements on the target. This servo-driven system provides sixty feet of longitudinal motion, twenty-five feet of lateral motion, and fifteen feet of vertical translation. The simulator facility has a total capability of 12 degrees of freedom.

This facility has been examined for application to the capture training problem, and it can easily be modified to accommodate the ESMRO training requirements. The entire CWP could be mounted on the load cell array as shown in Fig. 5-9 which is setup with a cabin directly behind it to simulate the time visibility conditions. The OSO could be attached to the moveable carriage with a harness that holds the OSO wheel by its lifting lugs and has a controlled spin mechanism to spin the OSO. The astronaut under training could then maneuver into contact with the OSO similar to orbit conditions by means of the computer control.

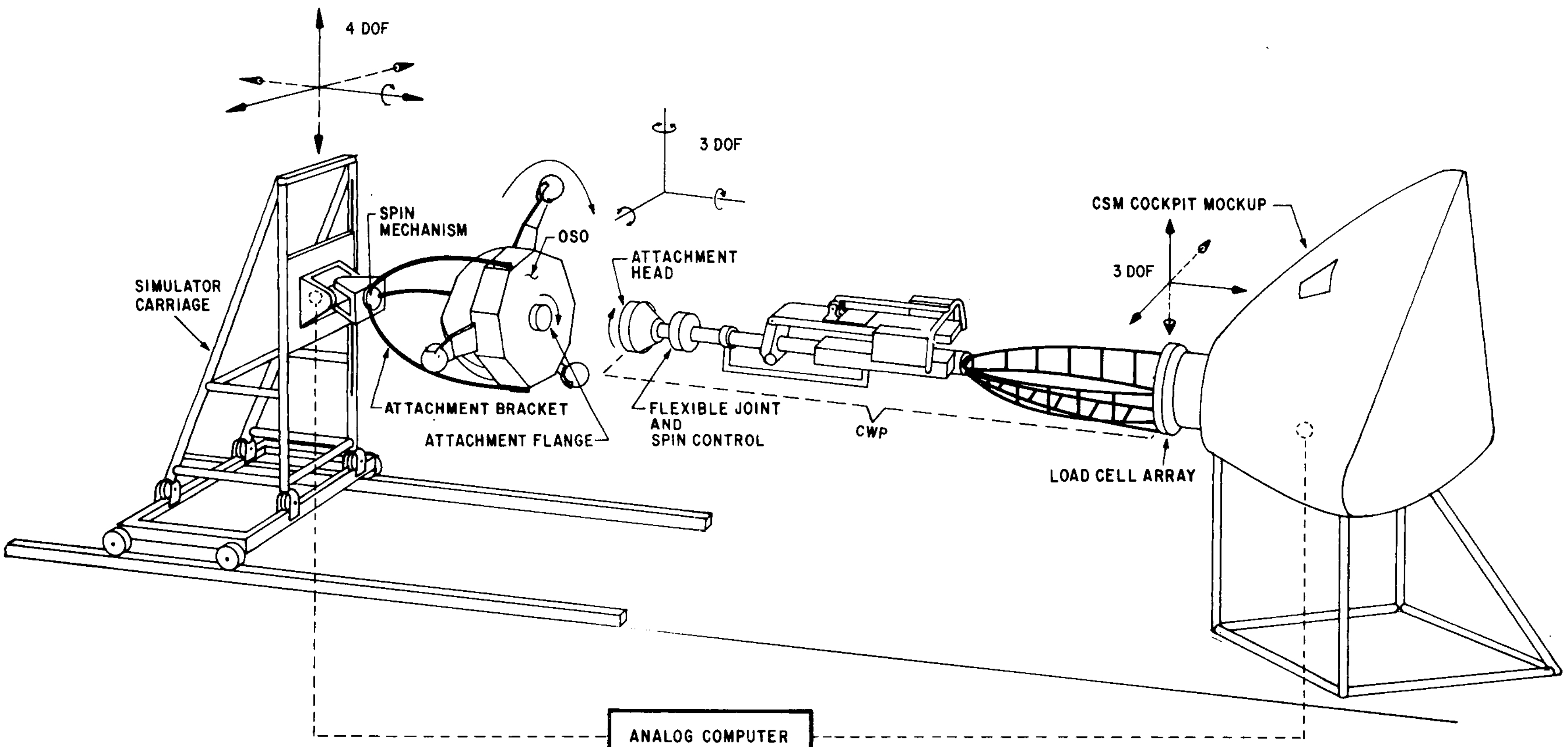
5.10.3 Useful EVA Work

The major training effort required for the ESMRO program is the EVA training for the useful work phase. This training will encompass the egress/ingress operations; the erection and maneuvering of the work platform; and the work operations on the OSO. All of these operations can be practiced in a sequence starting with one g shirt sleeve and suit tests and ending with pressurized suit tests under neutral bouyancy conditions and in zero g aircraft flights.

These operations can be practiced in the various simulators, such as the facility described above, at MSFC, or MSC. However, the most advantageous training for the EVA work to be performed on the OSO will be obtained in neutral bouyancy facilities. Major Aldrin's performance on Gemini XII has shown that similar work tasks can best be simulated under neutral bouyancy conditions. It is noted also that his timeline performance in orbit most exactly matched that in the neutral bouyancy facility.

For the ESMRO mission training, the CM tunnel, the CWP, and a mockup of the target OSO should be configured in the facility. The astronaut under training would be suited as in orbit, and would perform all of the experiment sequence from CM tunnel egressing and erecting the work platform, the operation of the tools on the OSO, and the stowage of equipment. The entire EVA phase of the mission could be evaluated and the procedural steps optimized.

Any procedural steps that can not be properly similated in the neutral bouyancy facility could be performed during zero g flights. Another tools operation training technique is the use of a glove equipped vacuum box. Similarily, over-pressurized suits could be used at one atmosphere laboratory conditions for early training on the useful work tasks.



SYSTEM SIMULATION - 10 DEGREES OF FREEDOM (DOF)

Fig. 5-9 CSM/OSO Capture Simulation

SECTION 6

MISSION 1 PROGRAM PLAN

Section 6
MISSION 1 PROGRAM PLAN

This section includes the details for the Mission 1 program plan. The three ESMRO missions have been identified by numerical sequence for convenience. The designation of the Mission 1 objective stated in Section 6.1 does not necessarily require that this objective be established in the first chronological mission. However, since Mission 1 is intended to prove out the capture technique on a nonoperating OSO, it is recommended that it be performed prior to Missions 2 and 3. Missions 2 and 3 are presented in Sections 7 and 8 respectively.

6.1 MISSION OBJECTIVE

The primary objective of Mission 1 is to rendezvous with, capture, and perform useful work on OSO II. The useful work is to consist primarily of material retrieval from OSO II. for analysis upon return to the surface. Secondary objectives include evaluation of capture technique, EVA technology and satellite release procedures.

6.2 MISSION CHARACTERISTICS

6.2.1 Time Frame

Mission 1 can be performed in the 1969 time frame.

6.2.2 Target OSO

The target OSO for Mission 1 is to be OSO II which was launched on 3 Feb 1965 from Cape Kennedy at a launch azimuth of 108 degrees. The OSO II satellite is illustrated in Fig. 1-1.

6.2.3 Orbital Conditions

6.2.3.1 CSM

The mission is to be initiated with the CSM in a 370 km (200 nautical miles) altitude parking orbit at an inclination of 32.85 degrees. The CSM is to be launched so that the longitude of its ascending node is within ±2 degrees of that of OSO II and approaching from the east.

6.2.3.2 OSO

OSO II should be in an orbit that has not significantly changed from the following parameters:

- Apogee 626 km (340 nm)
- Perigee 549 km (297 nm)
- Inclination 32.85 deg
- Period 96.5 min

6.3 MISSION OPERATIONS

The mission operations consist of the following functional steps:

- Capture mechanism docking
- Rendezvous maneuvers
- Precapture inspection during station keeping
- Capture
- Post-capture inspection and preparation
- Material retrieval
- Stowage of materials
- Release and capture mechanism jettison
- Post-release inspection

Each of these functional steps includes experiment tasks that are unique to the accomplishment of the mission. These experiment tasks are discussed in detail in this section; the tasks are itemized in Table 6-1. The detail of experiment description is intended to define the scope of the major experiment tasks and does not include details on experiments grouped as general mission support operations. Also indicated in this table is the reference section number and a designation of the experiment task priority. These priorities are defined as follows:

- Mission support operation: Experiment tasks required to perform the mission that must be accomplished before proceeding to the next functional step
- Primary: Experiment tasks that are essential to meeting the mission objectives
- Secondary: Experiment tasks that are generally performed after the primary tasks, and that increase the yield of the mission and supplement and accomplishment of the mission objectives

Table 6-1
SUMMARY OF MISSION 1 OPERATION TASKS

Experiment Task	Reference Section No.	Priority
Capture mechanism docking	6.3.1	MSO[a]
Rendezvous maneuvers	6.3.2	MSO
Precapture inspection during station keeping	6.3.3	-
Determination of OSO radioactive levels	6.3.3.1	MSO
Determination of OSO dynamics	6.3.3.2	MSO
Documentation photography	6.3.3.3	MSO
Capture operations	6.3.4	-
CSM maneuvers and OSO capture	6.3.4.1	MSO
Documentation photography	6.3.3.3	MSO
Postcapture inspection and preparations	6.3.5	-
Experiment preparation and radiation monitoring	6.3.5.1	MSO
OSO centering	6.3.5.2	MSO
OSO wheel power bus removal	6.3.5.3	MSO
Evaluation of mechanical freedom and damage	6.3.5.4	Primary
Documentary observing and photography	6.3.5.5	Primary
Material retrieval	6.3.6	-
NRL coronagraph occulting disk	6.3.6.1	Secondary
Control sensor assembly	6.3.6.2	Primary
Right-hand solar panel	6.3.6.4	Primary
HCO ultraviolet spectrometer	6.3.6.4	Primary
Ames emissivity sensor plate	6.3.6.5	Primary
U. of Minn. zodiacal light telescopes	6.3.6.6	Secondary
GSFC Ultraviolet spectrometer azimuth indexer	6.3.6.7	Secondary
U. of New Mex. gamma-ray telescope foil cover	6.3.6.8	Secondary
EVA documentation photography	6.3.6.9	Primary
Container stowage preparation	6.3.6.10	MSO
Refurbishment	6.3.7	-
Replenish pitch gas supply	6.3.7.1	Secondary
Return to CM and stowage of materials	6.3.8	MSO
Release and capture mechanism jettison	6.3.9	MSO
Post-release inspection	6.3.3	-
Determine OSO dynamics	6.3.3.2	MSO
Documentation photography	6.3.3.3	MSO

(a) MSO = mission support operation experiment task

As previously stated, each experiment task is described in further detail with respect to the following characteristics and requirements:

- Mission, or missions effectivity

- Experiment priority
- Purpose and objective
- Objective description
- Constraints
- Procedure (A detail procedure is defined for each experiment task. Each detail procedure was used in estimating the EVA and IVA times for the experiment tasks.) (Refer to Section 5.)
- Hazard conditions (defined as applicable)
- Accessibility
- Special tools and equipment
- Other support equipment
- Ground support equipment (defined as applicable)
- Astronaut training equipment
- Potential problem areas (defined as applicable)

A Mission 1 time line summary has been prepared and is shown in Table 6-2.

Table 6-2
MISSION 1 TIME LINE SUMMARY

Operation/Event	Experiment Priority	EVA (min)	IVA (min)	Accrued Mission Time (EVA + IVA) (min)
I Rendezvous operations				
CSM/CWP docking	MSO		25	25
CSM orbit transfer	MSO		44	69
Close rendezvous maneuvers	MSO		9	78
Night time station keeping	MSO		31	109
Circumnavigation	MSO		6	115
Precapture inspection	MSO		60	175
Night time station keeping	MSO		31	206
OSO capture maneuvers	MSO		6	212
Sub Total			212	

Table 6-2 (Cont.)

	Operation/Event	Experiment Priority	EVA (min)	IVA (min)	Accrued Mission Time (EVA + IVA) (min)
II	Work session No. 1				
	Start EVA-egress forward hatch	MSO	5	5	222
	Prepare equipment and OSO inspection	MSO	27	27	276
	Astronaut rest period		5		281
	Mount EVA cameras	P[b]	3	3	287
	Experiment preparation and radiation measures	MSO	36		323
	Satellite centering	MSO	21		344
	Astronaut rest period		6		350
	Wheel power bus removal	MSO	7		357
	Mechanical freedom and damage evaluation photos	P	26		383
	Removal coronagraph occulting disk and photos	S[c]	14		397
	Astronaut rest period		6		403
	Removal control sun sensor assembly and photos	P	19		422
	Astronaut rest period		6		428
	Stow experiments - return to CM	M	47	47	522
	Sub Total		228	82	
III	Astronaut 8 hr rest period				1002
IV	Work session No. 2				
	Start EVA-egress forward hatch	MSO	5	5	1012
	Prepare equipment reposition platform	MSO	27	27	1066
	Remove Ames emissivity plate and photos	P	26		1092
	Astronaut rest period		6		1098
	Remove zodiacal light tele-scope and photos	S	22		1120
	Astronaut rest period		5		1125
	Remove R.H. solar panel and photos[a]	P	120		1245
	Astronaut rest period		8		1253
	Stow experiments - return to CM	M	47	47	1347
	Sub Total		266	79	
V	Astronaut 8 hr rest period				1827
VI	Work session No. 3				
	Start EVA-egress forward hatch	MSO	5	5	1837
	Prepare equipment reposition platform	P	27	27	1891
	Remove HCO experiment and photos[a]	P	111		2002
	Remove gamma-ray telescope foils and photos	S	36		2038

Table 6-2 (Cont.)

Operation/Event	Experiment Priority	EVA (min)	IVA (min)	Accrued Mission Time (EVA + IVA) (min)
Astronaut rest period		6		2044
Remove UV azimuth indexer and photos	S	34		2078
Replenish pitch gas	S	25	8	2111
Prepare experiment stowage containers	MSO	8		2119
Astronaut rest period		5		2124
Stow experiments - return to CM	MSO	47	47	2218
Sub Total		304	87	
VII Release operations	MSO		23	2241
Mission 1 Totals		798	483	

(a) With astronaut rest periods as applicable
(b) P = primary objective
(c) S = secondary objective

6.3.1 Capture Mechanism Docking

MISSION(S) 1, 2, 3
EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: The purpose is to dock the CSM with the CWP in order to conduct the Experiments for Satellite and Material Recovery from Orbit (ESMRO) mission. This operation will require:

- Separating the CSM from the Saturn S-IVB
- Orienting CSM center line headon with the CWP docking collar
- Docking the CSM to the CWP
- Removing the CWP clear of the S-IVB

OBJECT DESCRIPTION: The CWP will be as shown in the conceptual picture, Fig. 4-23. The CWP docking collar will be identical to the LEM docking collar adapter in order to maintain compatibility with existing Apollo program hardware.

CONSTRAINTS:

- Astronaut to have line-of-sight vision to the CWP docking collar at start of docking operation
- The CWP docking collar to be illuminated.

PROCEDURE: Procedure to be determined as a part of Apollo Applications Program mission integration studies

HAZARD CONDITIONS: The proximity of two objects in a docking operation. (i.e. the Apollo CSM and Saturn S-IVB.)

SPECIAL TOOLS AND EQUIPMENT: Capture Work Platform. This system will consist of the following subsystems:

- Docking collar (with docking lights)
- Structure
- Attachment head
- Electrical umbilical
- Work platform (adjustable)
- Support equipment containers
- Artificial illumination
- Low pressure inert gas

OTHER SUPPORT EQUIPMENT: CSM with docking capability.

GROUND SUPPORT REQUIREMENTS: None

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with docking operating procedure
- Docking and release practice on spacecraft docking simulation device similar to CSM/LEM operations

6.3.2 Rendezvous Maneuvers

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To maneuver the Apollo CSM in an orbit transfer operation from the Apollo Applications Program orbit to the OSO orbit, in order to rendezvous with and capture the OSO satellite.

OBJECT DESCRIPTION: The rendezvous portion of the mission includes orbital transfer, circularization of the CSM orbit, circumnavigation of the CSM orbit, and night time station keeping. The plane change requirement and the launch window relationship between the initial CSM orbit and the OSO orbit must be considered before defining the orbit transfer. The rendezvous transfer maneuvers will be initiated during the night portion of the CSM orbit, so that rendezvous with the OSO will take place in the early day portion of the OSO orbit.

The transfer phase is expected to take 44 minutes. A terminal rendezvous phase will be completed to position the CSM with respect to the OSO for night time station keeping (approximately 31 minutes). At the start of the second orbit day, the CSM will enter into a circumnavigation phase, lasting approximately 60 minutes. During this phase, the CSM will maneuver around the OSO to conduct the precapture inspection experiments. Following circumnavigation, a second night time station keeping maneuver (31 minutes) will be conducted. The capture and containment operation will be initiated at the start of the third orbit day.

The AAP parking orbit is considered to be 370 km (200 nautical miles) with an orbit plane inclination of 32.85 degrees with the earth's equator. The CSM orbit is nearly circular with a plus 3σ eccentricity value of $e = 0.00045$. The OSO orbit is considered to have a semi-major axis of 6954 km (3776 nautical miles) at 32.85 ± 0.1 degree inclination. The OSO orbit is noticeably eccentric with a plus 3σ eccentricity of $e = 0.006$. The rendezvous approach recommended for the ESMRO missions is to launch the CSM coplanar with the OSO, into a 370 km parking orbit and then perform a coplanar transfer to the OSO orbit.

CONSTRAINTS:

- Allowable CSM SPS engine ΔV expenditure of 762 mps (2500 fps)
- Rendezvous with the OSO to be accomplished early in the day light portion of the orbit

PROCEDURE: Detail IVA astronaut procedures for performing the rendezvous maneuvers is to be determined as part of the system integration studies for the Apollo Applications Program.

SPECIAL TOOLS AND EQUIPMENT: None

OTHER SUPPORT EQUIPMENT:

- Apollo Command Service Module
- Communications link between CSM and ground radar tracking stations

GROUND SUPPORT EQUIPMENT:

- Ground radar tracking stations
- Ground communications link with MCC

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with orbit transfer procedures
- Familiarization and practice with orbit simulator

POTENTIAL PROBLEM AREAS:

- Rendezvous with a passive target satellite
- Establishing accurate OSO orbit ephermeris data

6.3.3 Precapture Inspection During Station Keeping

Prior to capture, the following inspections of the OSO satellite will be required:

- Determination of OSO radiation levels
- Determination of OSO dynamics
- Documentation photography

CONSTRAINTS: Presented below are the conditions and requirements which are in common with conducting these operations.

(1) Inspection operations will be conducted from within the CSM spacecraft

(2) The CSM must maneuver and station keep with the OSO (within 15 to 30 meters range) prior to capture and after release to obtain several unobstructed views. For determining spin rate, the CSM longitudinal axis will be maintained perpendicular to the OSO spin axis.

(3) The OSO must be illuminated.

(4) Radiation levels must be within crew safety limits.

(5) The OSO must not be contaminated by the RCS engine gases while the CSM is maneuvering and station keeping.

HAZARD CONDITIONS: Maneuvering and station keeping with the spinning OSO during circumnavigation.

ACCESSIBILITY: Good viewing will be possible through CSM spacecraft windows.

OTHER SUPPORT REQUIREMENTS:

- Command Service Module
- Intra vehicular astronaut (IVA)
- Communications link between CSM and ground
- Procedural transmission between CSM and ground
- Storage space in CSM for unexposed and exposed film container(s)

GROUND SUPPORT REQUIREMENTS:

- Communications link with ground tracking stations
- Procedural transmission between CSM and MCC
- Photographic developing and printing facilities (Sanborn recorder or equivalent to play back tape recorder for radiation data reduction)

ASTRONAUT TRAINING REQUIREMENTS:

- Use and familiarization with the spectrometer instrument
- Practice and operation with the two cameras
- Familiarization with the OSO and precapture, capture, release and post-release mission sequences
- Familiarization and observing practice with the spinning OSO

6.3.3.1 Precapture OSO Radioactive Radiation Levels

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To determine the OSO radioactive radiation types and levels and to ascertain if these levels are within crew safety limits before conducting EVA and exposing the astronaut to possible hazard. Specific measurements performed will yield the quantitative and qualitative characterizations of radiation levels associated with the OSO satellite with respect to particle type and dose rate. Based on these determinations, a go or no-go decision can be made with respect to continuing the ESMRO experiment mission.

OBJECT DESCRIPTION: A directional spectrometer will be utilized. The spectrometer will be comprised of a main scintillator, and anticoincidence scintillator, photomultiplier tube monitors, and a solid state pulse height analyzer. The total unit will weigh less than 15 pounds and can be handled by the astronaut inside the command module. The proton-electron spectrometer utilized will be similar to the one utilized for the MSC-2 experiment of the Gemini IV mission (Ref. 11).

PROCEDURE:

(1) Unstow instrument and position in spacecraft window for viewing the OSO during the circumnavigation phase

(2) Activate instrument in sufficient time (10 to 15 minutes)

(3) Monitor instrument during data taking periods while CSM spacecraft is circumnavigating the OSO satellite. Data taking periods and survey must be determined, but should not exceed 10 minutes total time.

(4) Take readings and ascertain if safe radioactive radiation levels on the OSO are present.

SPECIAL TOOLS AND EQUIPMENT: Directional spectrometer with astronaut readout capability

6.3.3.2 Determine OSO Dynamics, Precapture and Post-Release

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: Determine the satellite dynamics by visual methods prior to satellite capture and after release in order to:

- Compare observed satellite dynamics and spin rate with preflight predictions prior to OSO capture
- Ascertain that the satellite spin rate is within range limits of the capture mechanism capability
- Compare satellite dynamics and spin rate with post-flight determinations after OSO release

OBJECT DESCRIPTION: The OSO satellite is a spin stabilized satellite consisting of two main sections, the wheel and sail structures. Nominally, the wheel spins at 30 rpm. During the daylight portion of the orbit, the sail is fixed and points to the sun, while at night, the sail spins with the wheel. On Mission 1, OSO II will be nonoperating, therefore, the sail is expected to be spinning at the same rate as the wheel. Instrumentation of OSO II launched in 1965 indicates a spin rate decay of about 2 percent per month.

After a year with no spin rate corrections, the spin momentum is expected to be reduced to 80 percent of nominal. After 5 years of no spin rate corrections, the spin momentum and spin rate is expected to be reduced to one-third of nominal or approximately 10 rpm.

For Missions 2 and 3, the OSO wheel spin rates are expected to be nominal at 30 rpm with the sail stationary and pointing at the sun during satellite day when capture operations will be conducted.

PROCEDURE:

(1) Astronaut unstows stop watch and visual aid instrument.

(2) Astronaut notes and records verbally (tape recorder) overall OSO dynamics.

(3) While CSM is drifting past the OSO during circumnavigation, the astronaut makes visual determination of OSO spin rate.

(4) Ascertain if spin rate is within acceptable limits to proceed with capture operations.

SPECIAL TOOLS AND EQUIPMENT:

- Stop watch
- Visual aid for sighting at specific spot on OSO
- Tape recorder

6.3.3.3 Precapture, Capture and Release Documentary Photography

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To conduct documentary photography before any physical contact with the OSO is made and during the capture and release operations. The precapture and post-release documentary photography will be valuable in establishing the OSO configuration before and after conducting the ESMRO mission experiments. Movies taken during the capture and release operations will be valuable in establishing the OSO dynamics during capture and release. As a minimum, configuration views (stills) of the OSO from the front, back, right and left sides, top and bottom will be taken before capture and after release. Still photographs of opportunity such as damage and unusual features will be taken. Motion pictures of the capture and release operations will be taken. These pictures will reveal information concerning the OSO's stability prior to capture and its dynamic motion during the capture operations. Dynamic phenomena such as nutation and wobble of the OSO may be observed in the motion pictures during the capture operation. During the release of the OSO, tipoff perturbations and disturbances may be observed.

OBJECT DESCRIPTION: The OSO satellite is spin stabilized and consists of a wheel section and a sail section. Normally, the wheel section spins at 30 rpm, the sail is fixed during the day portion of the orbit and spins with the wheel during the night portion. On Mission 1, OSO II will be nonoperational; therefore, the sail is expected to be spinning at the same rate as the wheel. Since Missions 2 and 3 will be conducted with an operational OSO and the circumnavigation phase will be conducted during the orbit day portion, the astronaut can expect to see the wheel spinning with the sail fixed and pointed toward the sun.

PROCEDURE: Procedural steps for each task operation (i.e., precapture inspection, capture and release) will be determined as a part of overall mission planning. The tasks to be accomplished are as follows:

(1) Circumnavigate the OSO satellite with the CSM.

(2) Take colored still pictures of the OSO (manual camera operation).

- Front and back views
- Right and left side views
- Top and bottom views
- Views of opportunity

(3) Take color motion pictures of the OSO prior to capture operations and after release to document OSO dynamics. Take pictures at normal speed, (16 frames per second).

(4) Take colored motion pictures of the capture and release operations (fixed camera operation).

- Time-sequenced pictures to be taken from 15 feet to 5 feet at 6 frames per second. (Reverse procedure for release operations)
- Motion pictures to be taken from 5 feet through contact and until OSO is despun at normal speed (16 frames per second). (Reverse procedure for release operations)

(5) Return exposed film to earth in storage containers.

(6) Participate in post-flight analysis of photographs.

SPECIAL TOOLS AND EQUIPMENT:

- General purpose 70 mm Maurer still picture camera with f/2.8 80 mm f.l. lens and colored film

- Maurer 16 mm sequential camera, Model 308, with standard C mount lens and colored film and mounting brackets for fixed photography

- Storage containers for unexposed and exposed film

6.3.4 Capture Operations

Capture operations will entail:

- CSM maneuvers and OSO capture

- Documentation photography (see Section 6.3.3.3)

Presented below are the conditions and requirements which are in common with conducting these operations.

CONSTRAINTS:

(1) Capture and release operations must be accomplished while the CSM is in communication with a ground net tracking station and in the daylight orbit period.

(2) The CSM spacecraft must not be damaged.

(3) The operational OSO's (Mission 2 and 3) must not be damaged during the capture and release operations.

(4) Capture will be accomplished with an active noncooperative OSO satellite.

(5) The capture mechanism must have release capabilities.

(6) The OSO satellite must not be contaminated by RCS engine gas during capture maneuver operations.

HAZARD CONDITIONS: Maneuvering in close proximity with the spinning OSO satellite

ACCESSIBILITY: Reasonably good; however, maneuvering of the CSM spacecraft must be kept within close tolerances to effect a successful capture.

OTHER SUPPORT EQUIPMENT:

- Apollo Command Service Module

- Communications link between CSM and ground

GROUND SUPPORT REQUIREMENTS: Ground communications link with MCC

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with capture procedures
- Familiarization and practice with capture mechanism/OSO training simulator

6.3.4.1 Maneuvers and OSO Capture

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To capture the OSO satellite and control it so that EVA useful work tasks can be performed. The capture operation will consist of orienting and positioning the CSM spacecraft with respect to the OSO satellite, making contact between the OSO satellite and the capture mechanism, and capturing and controlling the OSO. Capturing and controlling the OSO entails despinning and stabilizing in order to continue with the ESMRO mission EVA work tasks.

OBJECT DESCRIPTION: The OSO satellite is spin stabilized operating in two dynamic modes. During orbital day, the wheel spins and a torque motor drives the sail and pointed instruments such that the upper section of the OSO remains fixed and pointed at the sun while the wheel section spins. The spin control system maintains the wheel section spinning between 30 and 39.6 rpm. During orbital night, the spin control system is turned off and bearing friction causes the sail section to spin with the wheel section. When this happens, the wheel section slows down, and the satellite stabilizes at a spin rate between 26.4 and 33.6 rpm. At slower rates, maximum unbalances of the pointed experiments cause a wobble of 10 minutes of arc of the satellite Z axis (spin axis).

Coupling with the OSO for capture can best be accomplished from the underside along the spin axis, preferably utliizing a capture device which grasps the OSO flange mount.

The approach to be utilized for capture is subject to the tradeoff considerations which are discussed in Section 4.

PROCEDURE: Detail IVA astronaut procedures for performing the capture operations will be determined as a part of system integration studies for the Apollo Application Program.

SPECIAL TOOLS AND EQUIPMENT: Capture Work Platform

- Structure
- Attachment head (with release capability)
- Flexible joint and spin mechanism (remote operation)
- Docking collar

- Other subsystems to support useful work

POTENTIAL PROBLEM AREAS: The capture operation will be one of the most critical of all the mission tasks, and will be conducted with a spinning noncooperative satellite. If this operation is not completed satisfactorily, the entire mission is aborted.

6.3.5 Post-Capture Inspection and Preparations

Post-capture inspections will entail:

- Experiment preparation and radiation monitoring
- OSO centering
- OSO wheel power bus removal
- Mechanical freedom and damage evaluation
- Documentary observations and photography

Presented below are the conditions and requirements which are in common with conducting these operations

CONSTRAINTS:

- Capture operation complete
- Precapture radiation levels determined to be within acceptable limits
- CSM cabin in depressurized condition
- All astronauts in pressurized space suits, EVA astronaut on life support umbilical
- Satellite commanded off
- Work platform adjusted to proper height
- Light sources operating
- Astronaut in outboard position
- Care not to contaminate any of the experiments scheduled for removal

HAZARD CONDITIONS:

- Normal edges and corners on sheet metal and machined surfaces
- Arms with high pressure gas spheres

- Close proximity of satellite bottom to astronaut helmet

ACCESSIBILITY:

- Good for conducting most of the experiments
- Fair for conducting experiments on bottom of satellite where overhead accessibility is required.

COMMON TOOLS AND EQUIPMENT

- Adjustable work platform with astronaut fixity
- Electrical umbilical
- Artificial illumination with portable light
- Remote wheel positioner and lock (flexible joint and spin mechanism)
- Power tool for driving adaptive heads
- Tool box
- Reel tether with clamp
- General purpose (GP) container

OTHER SUPPORT REQUIREMENTS:

- EVA astronaut with life support equipment
- EVA communications link with CM
- Procedural transmission from CM to EVA astronaut

GROUND SUPPORT REQUIREMENTS: Photographic developing and printing facilities

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with OSO and capture work platform mockup, no suit
- Familiarization with OSO, and capture work platform mockup; suit pressurized to 3.7 psig, environment 1 g
- Use of EVA tools
- Neutral buoyancy EVA simulation for time line evaluation

6.3.5.1 Preexperiment Preparation and Radiation Monitoring

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To position the astronaut and his support equipment for execution of experiment tasks and to measure radiation levels as backup to the measurements made from within the CM during the circumnavigation phase and for purposes of radiation monitoring.

OBJECT DESCRIPTION: The capture work platform (CWP) consists of the following major elements:

- Egress/ingress structure
- Adjustable work platform (with astronaut fixity)
- Support equipment containers (tool box, etc.)
- Experiment containers
- Structure
- Docking collar
- Attachment head
- Flexible joint and spin mechanism (remote operation)
- Electrical umbilical to CM
- Battery power supply
- Artificial illumination (with portable light)
- Mounting apparatus for remote camera operation
- Low pressure inert gas supply system
- Command console (portable, inside CM)

A concept of the CWP configuration is illustrated in Fig. 5-2 for the stowed, partially deployed, and fully deployed configurations. The stowed view depicts the CWP stowed with the OSO attached and despun. The Command Module has been depressurized and the forward hatch opened. The partially deployed view illustrates the astronaut positioned within the waist restraint support with the work platform still in a stowed position. The fully deployed view illustrates the work platform in the raised position with the astronaut moving into position to begin the useful work experiment tasks on the OSO. The work platform is designed to provide the astronaut with fixity and close proximity to the OSO for conducting useful work.

The dosimeter instrumentation is a small compact device which can be used either as a portable device or fixed in a given position. Specific details with regard to utilizing passive or active dosimeters and specific measurements to be performed with respect to quantitative and qualitative characterizations of the expected radiation levels will be determined. The dosimeter utilized will be similar to the one utilized for the D-9 experiment on the Gemini IV mission (Ref. 12).

PROCEDURE:

(1) Open forward hatch.

(2) Partially egress with tether attached.

(3) Measure radiation level.

(4) Connect electrical umbilical to CWP.

(5) Complete egress with equipment transfer tethers.

(6) Hand-walk along egress/ingress structure to boom

(7) Hand-walk along boom to platform.

(8) Attach equipment transfer tethers to boom.

(9) Deploy equipment stand from stowed position.

(10) Astronaut moves on to platform in inboard position.

(11) Grip equipment stand and engage foot restraints.

(12) Engage clips on waist restraint straps to equipment stand.

(13) Measure radiation level.

(14) Clip astronaut tether to equipment stand (tether still attached to astronaut and CSM).

(15) Energize CWP control console on equipment stand and release platform translation stow locks.

(16) Astronaut moves to platform outboard position.

(17) Move platform down to afford clearance of OSO during erection.

(18) Rotate platform to a position normal to axis of boom.

(19) Measure radiation level.

(20) Position working lights.

(21) Install EVA monitoring camera in fixed position.

(22) Check out OSO wheel lock system.

(23) Position platform by translation to wheel umbilical position.

(24) Measure radiation level.

(25) Astronaut moves inboard.

(26) Attach portable radiation dosimeter in monitoring position.

(27) Astronaut moves outboard

SPECIAL TOOLS AND EQUIPMENT:

- Radiation monitor (dosimeter)
- Equipment transfer tethers

6.3.5.2 OSO Centering

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To center the OSO satellite on the capture attachment head to obtain positive attachment to facilitate the conduct of useful work, and complete the initial steps necessary to release the satellite. This mission support operation will release the adhesive bond (or yoke arms) utilized in capturing and despinning the OSO satellite.

OBJECT DESCRIPTION: The OSO satellite capture mechanism will be as shown in the conceptual picture, Fig. 4-23. Incorporated within the attachment head will be an adhesive pad release mechanism and centering mechanism. The adhesive pad release mechanism will employ electrical heaters to heat the adhesive pads so that their bonds are released. The centering mechanism will mechanically grasp the OSO attachment flange and position the OSO about the centerline of the CWP boom.

PROCEDURE:

(1) Orient and lock wheel.

(2) Astronaut moves inboard.

(3) Unlatch centering mechanism device.

(4) Remove adhesive heating umbilical line from work platform.

(5) Attach umbilical line to adhesive attachment head.

(6) Activate adhesive heating circuit.

(7) Remove power tool from tool box.

(8) Attach power tool to adhesive release mechanism.

(9) As adhesive heats, break adhesive bond between adhesive pads and OSO.

(10) Remove adhesive heating umbilical line.

(11) Attach umbilical to work platform.

(12) Remove power tool from adhesive release mechanism.

(13) Attach power tool to satellite centering assembly.

(14) Center satellite about CWP boom center line.

(15) Remove power tool.

(16) Place power tool in tool box.

(17) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT: Adhesive heating capability (electrical umbilical)

6.3.5.3 OSO Wheel Power Bus Removal

MISSION(S) 1

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To remove the OSO external test console connector plug to assure that all power has been interrupted while conducting the useful work experiments

OBJECT DESCRIPTION: Power within the OSO satellite is interrupted unless a jumber circuit incorporated in the cover cap or plug of one of the OSO power console test connectors is installed. This operation is completed on the launch stand after the ground umbilical connector is removed. In orbit, internal OSO power can be interrupted by removing this plug. The connector and plug for OSO II are Bendix part numbers PT02P-11S-005 and PT06P-18-005 respectively. The plug and connector are located on the bottom side of compartment No. 8 adjacent to two other console test connectors which are covered with Bendix cap receptacles. These connectors are illustrated in OSO photograph Fig. 5-7.

PROCEDURE:

(1) Orient and lock wheel with connectors at work station.

(2) Astronaut moves inboard.

(3) Attach reel tether to connector removal tool.

(4) Remove connector removal tool from tool box.

(5) Position removal tool on connector.

(6) Remove connector.

(7) Place connector in GP container.

(8) Place connector removal tool in tool box.

(9) Remove reel tether.

(10) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT: Connector plug removal tool.

POTENTIAL PROBLEM AREAS: Connector may not be removable due to cold welding.

6.3.5.4 Mechanical Freedom and Damage Evaluation

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To manually rotate sail with respect to the wheel and move the pointed instruments with respect to the sail to determine if the moving parts have cold welded after the long duration of inactivity in space. Further objectives of this experiment are to inspect the OSO satellite for physical damage and photograph any damage found. It is anticipated that both the sail and pointed experiments will move freely since it is believed that cold welding will not have occurred. Possible damage due to micrometeroid bombardment is very unlikely since the reflective surface area of the OSO is less than one square meter. No major physical damage is expected either.

OBJECT DESCRIPTION: The OSO configuration is shown in Fig. 1-1 and consists of a spinning wheel section and a sail structure which is oriented toward the sun during daylight operation. Within the sail structure are the pointed instruments which are free to gimbal in pitch elevation relative to the sail structure. Normally, both the pointed instruments and the sail structure move with relatively little force.

PROCEDURE:

(1) Astronaut rotates satellite to observe gross damage while in outboard position.

(2) If damage has occurred, astronaut positions wheel for picture taking experiment (Ref. Section 6.3.5.5.)

(3) If no damage is evident, astronaut positions wheel so compartments Nos. 8 and 9 are in line of sight and locks wheel.

(4) Astronaut moves inboard.

(5) Astronaut rotates sail so that he can reach NRL boom. If sail does not move relative to wheel, use alternate procedure. NOTE: Return from alternate procedure.

(6) Astronaut grips NRL coronagraph boom and moves pointed experiments up and down to check elevation gimbal freedom. If gimbal is frozen, proceed to step (12).

(7) Attach reel tether to elevation lock.

(8) Remove elevation lock from tool box.

(9) Attach elevation lock to top of sail.

(10) Position pointed experiments and attach elevation lock to NRL boom.

(11) Remove reel tether from elevation lock.

(12) Position sail for next experiment, if sail does not rotate relative to wheel, go to 18.

(13) Attach reel tether to sail lock.

(14) Remove sail lock from tool box.

(15) Position sail lock and lock sail to wheel.

(16) Remove reel tether.

(17) Attach sail lock tether to sail.

(18) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Sail lock
- Pointed experiment package elevation lock

ALTERNATE: Mechanical Freedom and Damage Evaluation

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: This procedure is followed in the event that the sail is frozen to the wheel and there is no freedom of movement.

PROCEDURE:

(1) Astronaut moves outboard.

(2) Astronaut rotates satellite and locks wheel positioner so that NRL coronagraph boom is in position.

(3) Astronaut moves inboard.

(4) Return to Step (6) of experiment procedure.

POTENTIAL PROBLEM AREAS:

(1) Lack of sail rotation may restrict working areas of other experiments and increase potential contamination to subsequent experiments.

(2) Accessibility to other mission experiments may be restricted.

6.3.5.5 Post-Capture Documentary Observing and Photography

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To conduct visual and photographic documentation of the OSO satellite after capture operations are completed (during useful work tasks). Visual and photographic determination of the OSO appearance and configuration, will establish before and after historical records before and after experiment tasks are conducted. As a minimum, colored pictures of before and after views will be taken for each experiment conducted on Mission 1. Furthermore, colored photographs of opportunity will be taken as necessary and convenient during the conduct of each experiment.

OBJECT DESCRIPTION: The OSO satellite is illustrated in Fig. 1-1. Before and after pictures and observations of particular interest will be taken for the following experiments and subjects:

- Removal of control sensor assembly
- Removal of right hand solar panel
- Removal of HCO instrument
- Removal of Ames emissivity plate
- Removal of NRL occulting disk
- Removal of University of Minnesota telescopes
- Removal of University of New Mexico foil covers
- Removal of GSFC azimuth indexer

PROCEDURE: (for each picture sequence)

(1) Remove camera with tether from stowed position.

(2) Direct light on subject area.

(3) Focus and take picture of subject area.

(4) Return camera to stowed position.

SPECIAL TOOLS AND EQUIPMENT:

- General purpose 70 mm Maurer still picture camera with f/2.8 80 mm f. l. lens and colored film with tether
- Storage containers for unexposed and exposed film
- Artificial illumination
- Place to store camera between picture taking operations

POTENTIAL PROBLEMS: Adequate lighting of the areas to be photographed.

6.3.6 Material Retrieval

Material retrieval will entail the following experiments:

- NRL coronagraph occulting disk
- Control sensor assembly
- Right hand solar panel
- HCO ultraviolet spectrometer
- Ames emissivity sensor plate
- University of Minnesota zodiacal light telescopes
- GSFC UV spectrometer azimuth indexer
- University of New Mexico gamma-ray telescope foil cover
- EVA documentation photography
- Container stowage preparation

CONSTRAINTS: Presented below are the conditions and requirements which are in common with conducting these operations.

- Satellite commanded off
- Wheel umbilical power bus removed
- Sail locked to wheel
- Pointed instrument elevation frame locked
- Artificial light sources operating
- Work platform adjusted to proper height
- Astronaut in outboard position
- All retrieved items tethered before removing from satellite
- No damage and contamination of items to be retrieved

- Protective covers to be provided for optical lens and apertures where applicable
- Inert gas storage containers to be provided to protect items to be retrieved
- EVA astronaut to be tethered and be in view of the IVA astronaut while conducting EVA

HAZARD CONDITIONS:

- Normal edges and corners on sheet metal and machined surfaces
- Arms with high pressure gas spheres
- NRL occulting disk and boom
- Protruding screw shanks
- Metal chips from screw head removal operation
- Ragged core drill holes in exposed sail structure
- Wire bundle cut ends
- Handling experiment packages freed from satellite
- Aperture doors around wheel rim panel
- Antennae under wheel section

ACCESSIBILITY: Accessibility ranges from good to difficult depending on the experiment task. Experiments rating good accessibility are:

- NRL occulting disk
- Control sensor assembly
- Ames emissivity sensor plate
- University of Minnesota zodiacal light telescopes
- University of New Mexico gamma-ray telescope foil cover
- EVA documentation photography

Experiments rating fair to poor accessibility are:

- GSFC UV spectrometer azimuth indexer
- Container stowage preparation

Experiments with a rating of difficult are:

- Right hand solar panel
- HCO ultraviolet spectrometer

COMMON TOOLS AND EQUIPMENT:

- Adjustable work platform with astronaut fixity
- Electrical umbilical
- Artificial illumination with portable light
- Remote wheel positioner and lock
- Device for locking sail
- Device for locking pointed instrument elevation frame
- Power tool for driving adaptive tools
- Pry bar with tether
- Screw head removal tool
- Wire bundle cutter with tether
- Bolt cutter with tether
- Reel tether with clamp
- Tool box
- General purpose (GP) container

OTHER SUPPORT REQUIREMENTS:

- IVA astronaut
- EVA astronaut with life support equipment

- EVA communications link with CM
- Procedural transmission from CM to EVA astronaut
- Storage space in CM for returning storage containers to earth

POTENTIAL PROBLEM AREAS:

- Removal of instrument mounting screws due to accessibility and the use of Loctite during installation.
- Removal of HCO instrument from stub shaft.

GROUND SUPPORT REQUIREMENTS:

- Clean room laboratory for post-flight analysis.
- Vacuum laboratory for post-flight analysis.

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with OSO mockup, no suit
- Familiarization with OSO and capture work platform mockup; suit pressurized to 3.7 psig, environment 1 g
- Use of EVA tools
- Neutral buoyancy EVA simulation for time line evaluation

6.3.6.1 Retrieval of NRL Coronagraph Occulting Disk

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To remove the NRL coronagraph occulting disk for post-flight material analysis and to determine if "whiskers" have grown in the serrated edge of the disk. Current knowledge about the molecular behavior of metals and alloys after long term exposure to space environment is very limited.

OBJECT DESCRIPTION: The disk is small, less than 2 inches in diameter by 1/8 inch thick and weighs only a few ounces. The disk is held in place by a standoff arm on a boom extended directly in front of the coronagraph telescope. The disk is shown in Fig. 6-1 and has a serrated perimeter edge. The disk standoff arm is secured to the boom by two Allen head screws with washers.

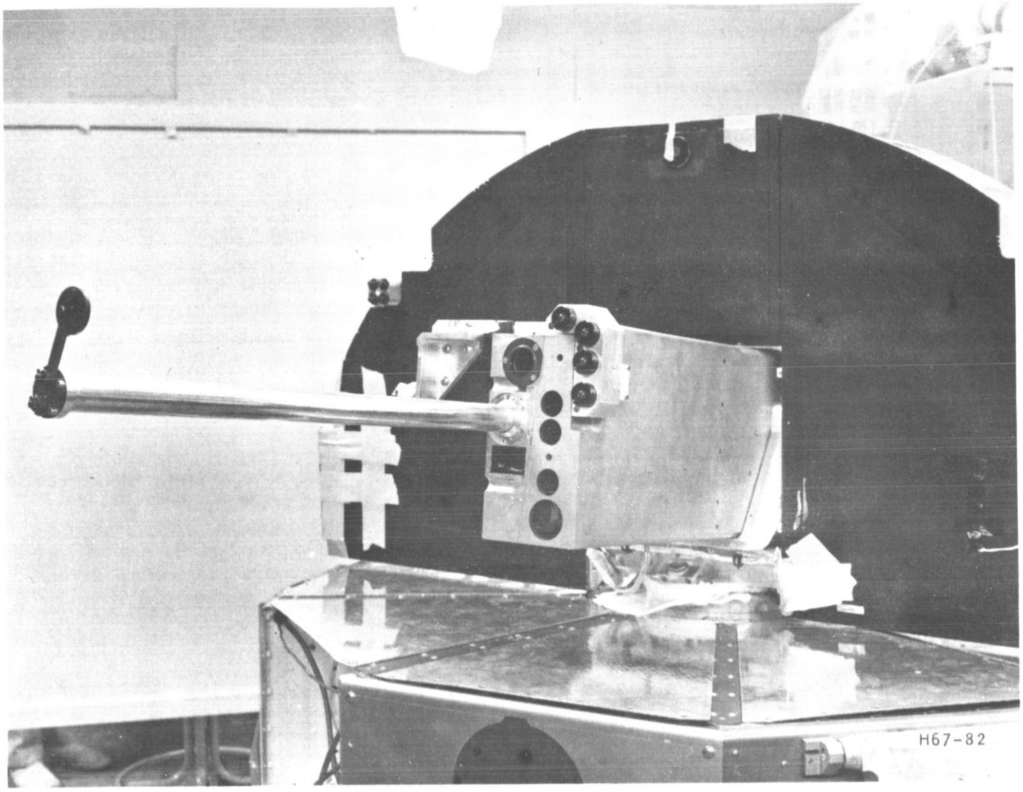


Fig. 6-1 NRL Experiment - Front View

REMOVAL PROCEDURE:

(1) Astronaut positions and locks wheel.

(2) Astronaut remains in out board position.

(3) Attach reel tether to rigid tether.

(4) Attach rigid tether to standoff arm.

(5) Remove reel tether.

(6) Remove power tool from tool box.

(7) Insert Allen head driving tool.

(8) Position powered screw driver at first screw.

(9) Remove screw. If screw fails to extract, use alternate procedure.

(10) Place screw and washer in general purpose container.

(11) Repeat steps (8) through (10) for second screw.

(12) Remove driving tool from power tool.

(13) Stow driving tool in tool box.

(14) Stow power tool in tool box.

(15) Attach reel tether to rigid tether.

(16) Open container.

(17) Remove rigid tether from standoff arm.

(18) Stow occulting disk and standoff arm in container.

(19) Close and lock container.

(20) Open general purpose container.

(21) Remove reel tether from rigid tether.

(22) Release reel tether.

(23) Stow rigid tether.

(24) Close general purpose container.

(25) Astronaut is in outboard position.

SPECIAL TOOLS AND EQUIPMENT:

- Allen head driving tool
- NRL occulting disk rigid tether
- Inert gas storage container for occulting disk and standoff arm

ALTERNATE: Retrieval of NRL Coronagraph Occulting Disk

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: This procedure is used in the event that one or both of the Allen head mounting screw heads is rendered unserviceable or if one or both of the mounting screws cannot be removed.

PROCEDURE:

(1) Position powered screw driver at first of 4 flange mounting screws.

(2) Remove screw - if screw fails to extract, proceed to alternate Step (4).

(3) Place screw with washer attached in general purpose container.

(4) Repeat Steps (1) through (3) for the three remaining screws.

(5) If the 4 screws have been removed, return to Step (12) of experiment procedure.

(6) Remove driving tool from power tool.

(7) Stow driving tool.

(8) Stow power tool.

(9) Astronaut abandons experiment and moves in outboard position.

6.3.6.2 Retrieval of Control Sensor Assembly

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To remove the control sensor assembly mounted on the Harvard College Observatory instrument for return to earth for post-flight analysis. Solar cells for control systems are a key part of many satellites and any knowledge that can be gained which will lead to improved performance, extended life, or improved designs will be of considerable value to future space programs. Further, this assembly must be removed before the HCO instrument which is another primary experiment task on this mission can be removed. It is anticipated that the assembly can be readily removed. Post-analysis inspection of the silicon solar cells is expected to reveal engineering and scientific information with regard to the following

- Surface degradation effects on solar cell lens
- Degradation effects on the knife-edge reticle which is deposited on the deep red filter

OBJECT DESCRIPTION: The control sensor assembly (detailed on BBRC drawing D7993, Fine Eye Assembly, Harvard) an L-shaped aluminum block that is approximately 3-1/2 inches by 1 inch along one leg, 4 inches by 1 inch along the second leg, 2 inches deep, and has five photovoltaic silicon solar cells located on the front side. This assembly is pictured in Fig. 6-2 and is held in place by three NAS1218C06-8 screws and NAS620A6L washers. The screws insert into Hilicoil inserts with six to seven threads of engagement. These inserts are in three aluminum bearing pads which are fixed to the HCO experiment with an epoxy bond. These pads may fall free when the assembly is removed. The assembly has recessed holes in the front side for the attachment screw heads. The electrical connection between the control sensor assembly and the HCO experiment is through an eight-pin Winchester MRE 8 P-N connector which is easily uncoupled by pulling the assembly forward. The total weight of the control sensor assembly is less than one pound.

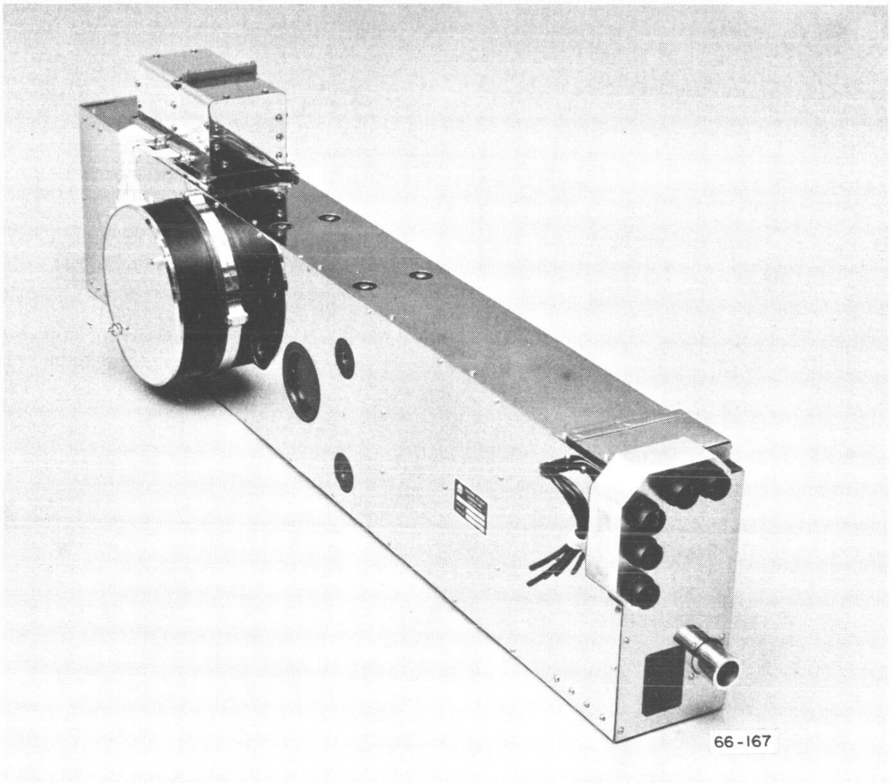


Fig. 6-2 HCO Experiment Side View

REMOVAL PROCEDURE:

(1) Orient and lock wheel with NRL boom to right of astronaut

(2) Astronaut moves inboard.

(3) Attach reel tether to protective cover.

(4) Remove protective cover from container.

(5) Attach protective cover to eye block.

(6) Remove power tool from tool box.

(7) Install driving tool.

(8) Position driving tool in first screw.

(9) Remove first screw. If screw fails to extract, proceed to Step (11).

(10) Place screw, and washer if attached, in general purpose container.

(11) Repeat Steps (8) through (10) for second and third screw. If any screws fail to extract, use alternate procedure.

(12) Place driving tool in tool box.

(13) Place power tool in tool box. NOTE: Return from alternate procedure.

(14) Open control sensor assembly container.

(15) Remove pry bar with tether attached from tool box.

(16) Pry control sensor assembly loose from connector.

(17) Place pry bar in tool box.

(18) Remove control sensor assembly

(19) Place control sensor assembly in container.

(20) Remove reel tether.

(21) Close container.

(22) Astronaut moves outboard.

ALTERNATE: Retrieval of control sensor assembly

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: This procedure is used in the event that one or all of the NAS1218-C06-8 mounting screw heads is rendered unserviceable or if any or all of the mounting screws cannot be removed.

PROCEDURE:

(1) Place driving tool in tool box.

(2) Install screw head removal tool on power tool.

(3) Position removal tool over defective screw.

(4) Remove screw head.

(5) Repeat Steps (3) and (4) as required.

(6) Place screw head removal tool in tool box.

(7) Place power tool in tool box.

(8) Return to Step (14) in experiment procedure.

6.3.6.3 Retrieval of Right Hand Solar Panel

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To remove the right hand solar panel for return to earth for post-flight material analysis. Any knowledge that can be gained which will lead to improved performance, extended life, or improved designs will be of considerable value to future space programs. Furthermore, removal of this solar panel is necessary to gain access to the forward mounting screws which must be removed to retrieve the HCO instrument which is another primary experiment on this mission. Post-flight analysis inspection of the silicon solar cells is expected to reveal engineering information with regard to the following

- Transient effects (important for operating systems, but difficult to evaluate without recovering a complete unit which has operated in space)
- Surface degradation effects
- Semiconductor degradation due to local changes in crystal lattice (Laboratory simulation is inadequate, because of the limited knowledge of the fluxes and energy spectra of electrons and protons in space.)

OBJECT DESCRIPTION: The right hand solar panel [detailed on BBRC drawing C8318 Silicon Cell Assembly (SCD).] is quarter-circle shaped, approximately 17 inches along the base and 21 inches high. The solar panel is approximately one inch thick and is composed of an outer layer of silicon solar cells. Each cell has a 0.006 inch thick cover glass with an ultraviolet reflective coating on one side and a red antireflective coating on the other side.

The silicon cells are bonded to a substrate panel with a silicon adhesive and the substrate is bonded onto honeycomb with a fiber glass layer and epoxy. The honeycomb is fastened onto the sail lattice structure by screws through the sail structure into inserts which are imbedded in the honeycomb. There are two layers of black rubber tape (3M Scotch or equivalent) between the honeycomb and the sail structure. There are twenty-one NAS1352C-06-6 screws and NAS620A6 washers holding the solar panel onto the sail structure. The inserts in the honeycomb are DELRON 465G632-06. The silicon cells are soldered together into modules of four or five cells, and the modules are interwired with the wires running along paths on the back of the solar panel to a common terminal at the inside and base of the panel. In conjunction with the silicon cells, there are four temperature probes and associated wiring which are located on the back side of the panel. Once the screws holding the solar panel have been freed, the panel may be pulled away from the sail structure approximately 1/2 inch in order to facilitate wire cutting operations.

REMOVAL PROCEDURE:

(1) Orient and lock wheel with solar panel facing astronaut.

(2) Astronaut moves inboard.

(3) Attach reel tether to template.

(4) Remove template.

(5) Position template over right hand solar panel.

(6) Lock template to solar panel at three positions along edge.

(7) Remove power tool from tool box.

(8) Attach solar cell core drill to power tool.

(9) Position core drill in template for first core.

(10) Cut through solar cell.

(11) Remove power tool from first core.

(12) Repeat Steps (9), (10), and (11) for balance of 20 screws.

(13) Take two minutes rest after each seven drilling operations.

(14) Place solar cell core drill in tool box.

(15) Attach solar panel core drill to power tool.

(16) Position solar panel core drill in template for first panel core.

(17) Cut through solar panel.

(18) Remove core drill from solar panel and template.

(19) Repeat Steps (16), (17), and (18) for balance of 20 screws.

(20) Take two minute rest period after each seven drilling operations.

(21) Place solar panel core drill in tool box.

(22) Place power tool in tool box.

(23) Astronaut moves outboard.

(24) Orient wheel with right edge of sail in line of sight to astronaut, and lock wheel.

(25) Astronaut moves inboard.

(26) Remove short tether from tool box.

(27) Attach short tether to solar panel.

(28) Attach free end of tether to sail frame.

(29) Attach reel tether to variable wedge tool.

(30) Remove variable wedge from tool box with tether.

(31) Install variable wedge between solar panel and sail frame.

(32) Attach variable wedge tether to sail frame.

(33) Remove reel tether from variable wedge.

(34) Orient portable light between solar panel and sail frame.

(35) Remove solar panel special wire bundle cutter and tether from tool box.

(36) Position cutter over first wire bundle.

(37) Cut wire bundle.

(38) Position variable wedge as required.

(39) Repeat Steps (36) through (39) to cut additional wire bundles as required.
NOTE: Return from alternate procedure.

(40) Place cutter in tool box.

(41) Astronaut moves outboard.

(42) Orient wheel as necessary to complete wire bundle, cutting and lock wheel.

(43) Astronaut moves inboard.

(44) Repeat Steps (36) through (38) until all wire bundles are cut.

(45) Place cutter in tool box.

(46) Attach reel tether to variable wedge.

(47) Remove variable wedge tether from sail frame.

(48) Place variable wedge in tool box.

(49) Remove reel tether from wedge.

(50) Open solar panel container.

(51) Attach reel tether to solar panel.

(52) Remove solar panel short tether.

(53) Attach free end to sail frame.

(54) Place solar panel and template in container.

(55) Remove reel tether.

(56) Close container.

(57) Stow solar panel short tether.

(58) Stow portable light.

(59) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Solar panel drill template and protective cover
- Solar cell core drill
- Solar panel core drill
- Variable angle wedge with tether
- Wire bundle cutter with tether

- Solar panel short tether

- Inert atmosphere storage container for solar cell array and template (18 by 22 by 2 inches)

POTENTIAL PROBLEM AREAS:

- Wire bundles which do not permit sail to be wedged back for cutting

- Bonding of solar panel to sail frame because of adhesive tape used between frame and panel.

- Contamination of solar panel during removal operations

ALTERNATE: Retrieval of Right Hand Solar Panel

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: This procedure is used in the event that access to cutting of the wire bundles is not readily attainable.

PROCEDURE:

(1) Return solar panel special wire bundle cutter to tool box.

(2) Release sail clamp; if sail does not rotate relative to wheel, go to alternate Step (5).

(3) Position sail (back of sail in astronaut line of sight).

(4) Lock sail clamp and go to alternate Step (8).

(5) Astronaut moves outboard.

(6) Orient wheel to position sail as described in Step (3) and lock.

(7) Astronaut moves inboard.

(8) Remove cutter, tether attached, from tool box.

(9) Cut all accessible solar panel harness hold-downs.

(10) Return to Step (40) of experiment procedure.

SPECIAL TOOLS AND EQUIPMENT: Solar panel special wire bundle cutter with tether

ACCESSIBILITY: Cutting operation is limited to outer periphery of sail structure.

6.3.6.4 Retrieval of Harvard College Observatory Ultraviolet Spectrometer Instrument

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To remove the HCO instrument for return to earth for post-flight system performance and material analysis. Dr. L. Goldberg of Harvard has requested the return of the instrument to determine the cause of the failure of the high voltage electronics upon turn-on, and to study degradation in the instrument optics due to long term exposure to space environment.

The retrieval and evaluation of optical components will be of great value to future space programs. Numerous space experiments and instruments employ optical components. The complete affects of the total space environments on optical units cannot be simulated nor (in many cases) accurately predicted. The recovery of optical components may provide correction factors which, when applied to the results of various experiments, could increase their accuracy and affect the conclusions. The data will also aid in predicting or improving the useful life of optical components for future space applications. Post-analysis inspection of the HCO instrument is expected to reveal engineering and scientific information with regard to the following:

- Cause of failure of high voltage electronics upon turn-on
- Surface damage of highly polished surfaces due to micrometeorite impacts and their resultant sputtering
- Browning or yellowing discolorations of optics which decrease transmission effects as a function of wavelength
- Shifts in index of refraction
- New or enhanced absorption bands
- Devitrification which crystallographically and physically alters glass structure and renders glass nonhomogeneous and increases absorptivity
- Contamination due to sputtering and outgassing of other materials on the satellite and photopolymerization of condensed films

OBJECT DESCRIPTION: The instrument is approximately 38 inches long, 8 inches high and 4 inches wide. The instrument is pictured in Fig. 6-2. Located on the front end is the control sensor assembly and wire bundle which must be removed (Section 6.3.6.2) in order to slide the instrument out of the elevation frame. Also located on the front end is a ballast weight which must be removed. On the rear end and top is a Harvard R. P. T. Assembly (BBRC drawing D8727) which protrudes approximately 3 inches above the HCO instrument. Attached to this assembly is the flex print cable (BBRC drawing D8333) which must be cut to release the instrument. Attached to the rear end and side is a Decoder Assembly which must be removed in order to stow the instrument for storage in the CM. The decoder is attached with four Phillips head screws and washers. Associated with this decoder is a wire bundle terminating into two MM-44-22PSK Continental connectors which must be cut. The HCO instrument is held in place by three Button Socket Head 3/8 - 24 by 3/4 screws and three AN960C616L washers, one in back and two in front. The screws hold the instrument against a boss in the elevation frame for support. Loctite Grade E was used on the screws with 200 in-lbs of torque applied during final installation.

Constant force of the torquing tool will be required against the screws to break them loose. If the screws cannot be loosened, the instrument cannot be removed. There is fair access to the rear screw. Access to the two front screws is through the sail structure. Reasonable access is obtained after the right hand solar panel (BBRC drawing C8318) has been removed (Section 6.3.6.3). Movement of the instrument up and down is required to gain access to both the front and back screws.

PROCEDURE:

(1) Orient and lock wheel.

(2) Astronaut moves inboard.

(3) Attach reel tether to aperture cover plate.

(4) Remove cover plate from container.

(5) Install protective aperture cover plate on instrument.

(6) Remove reel tether from protective cover.

(7) Orient portable light to front elevation gimbal screws.

(8) Remove power tool from tool box.

(9) Install right angle driving tool.

(10) Position driving tool on upper screw.

(11) Adjust driving tool axial load.

(12) Remove upper screw. If screw fails to extract use alternate procedure No. 1.

(13) Place No. 1 screw in general purpose container.

(14) Positioned elevation clamp (down position).

(15) Position driving tool on second screw.

(16) Adjust driving tool axial load.

(17) Remove No. 2 screw.

(18) Place No. 2 screw in general purpose container.

(19) Place driving tool in tool box.

(20) Stow portable light.

(21) Install driving tool (connector block).

(22) Position tool over No. 1 screw.

(23) Remove screw with washer attached. If screw fails to extract, proceed to Step (25).

(24) Place screw with washer attached in general purpose container.

(25) Position tool on No. 2 screw.

(26) Remove screw. If screw fails to extract, proceed to Step (28).

(27) Place screw with washer in general purpose container.

(28) Stow driving tool in tool box.

(29) Install balance weight, driving tool on the power tool.

(30) Position tool on first screw.

(31) Remove screw and place in general purpose container. If screw fails to extract, proceed to Step (32).

(32) While holding balance weight with one hand, remove second screw and place in general purpose container. If any screws [Steps (22) through (32)] fail to extract, use alternate procedure No. 2.

(33) Place balance weight in general purpose container.

(34) Stow balance weight driving tool in tool box.

(35) Stow power tool in tool box.

(36) Remove cutter with tether attached from tool box.

(37) Grip connector block with one hand and position block.

(38) With other hand, cut wire bundle close to side of instrument package.

(39) Stow connector block in general purpose container.

(40) With cutter tool, push short end of wire bundle into instrument box.

(41) Place cutter in tool box.

(42) Attach tether to sail.

(43) Remove sail clamp and retain in hand.

(44) With other hand reposition sail (rotate sail 90 degrees to the right)

(45) Install sail clamp.

(46) Remove reel tether.

(47) Attach reel tether to protective ion cover plate.

(48) Remove plate from container.

(49) Install protective ion cover plate on instrument.

(50) Remove reel tether from protective cover.

(51) Remove flex print cutter (tether attached) from tool box.

(52) Cut flex print.

(53) Stow flex print cutter in tool box.

(54) Orient portable light for decoder removal.

(55) Remove power tool from tool box.

(56) Install driving tool on power tool.

(57) Position tool on first screw of decoder.

(58) Remove screw. If screw fails to extract, proceed to Step (60).

(59) Place screw with washer attached into general purpose container.

(60) Position driving tool on second screw.

(61) Remove No. 2 screw. If screw fails to extract, proceed to Step (63).

(62) Place No. 2 screw in general purpose container.

(63) Position driving tool on No. 3 screw.

(64) Remove No. 3 screw. If screw fails to extract, proceed to Step (66).

(65) Place No. 3 screw in general purpose container.

(66) Position driving tool on No. 4 screw.

(67) Remove No. 4 screw. If screw fails to extract, proceed to Step (68).

(68) Place No. 4 screw in general purpose container. If screws fail to extract, use alternate procedure No. 3.

(69) Stow driving tool in tool box.

(70) Stow power tool in tool box. NOTE: Return from alternate procedure No. 3.

(71) Stow portable light.

(72) Remove cutter (tether attached) from tool box.

(73) Cut wire bundle between NRL and Harvard instruments.

(74) With other hand grip position decoder.

(75) Cut first wire bundle from Harvard to decoder.

(76) Attach reel tether to decoder.

(77) Position decoder.

(78) Cut second wire bundle.

(79) Remove reel tether.

(80) Stow decoder in general purpose container.

(81) Stow wire cutter in tool box.

(82) Remove short tether from tool box.

(83) Attach short tether to Harvard instrument and sail frame.

(84) Orient portable light for screw removal.

(85) Remove power tool from tool box.

(86) Install right angle driving head.

(87) Position power tool on rear mounting screw.

(88) Adjust driving head axial load, and spanner lock.

(89) Remove screw. If screw fails to extract, use alternate procedure No. 4.

(90) Place screw in general purpose container.

(91) Stow right angle driving head in tool box.

(92) Stow power tool in tool box.

(93) Stow portable light.

(94) Remove pry bar (tether attached) from tool box.

(95) Pry Harvard instrument off stub shaft.

(96) Stow pry bar in tool box.

(97) Astronaut moves outboard.

(98) Release wheel lock and position wheel rear of Harvard instrument with line of sight of astronaut.

(99) Lock wheel.

(100) Open Harvard instrument storage container.

(101) Astronaut moves inboard.

(102) Attach reel tether to the rear of Harvard instrument.

(103) Remove one end of short tether from instrument.

(104) Attach tether end to sail frame.

(105) Work Harvard instrument out of elevation gimbal; as astronaut removes instrument, he moves platform outboard, until instrument is freed.

(106) Stow instrument package in container.

(107) Remove reel tether.

(108) Close container.

(109) Astronaut is outboard, at completion of instrument retrieval.

SPECIAL TOOLS AND EQUIPMENT:

- Protective cover for instrument aperture.
- Protective cover for instrument ion trap
- Connector block screw driving tool (for Phillips head MS-35216-18 screws)
- Right angle screw driving tool
- Balance weight screw driving tool
- Decoder screw driving tool
- Flex print cutter with tether attached
- HCO short tether with double clamps
- Inert gas storage container (50 by 15 by 6).

ALTERNATE: Retrieval of Harvard College Observatory Ultraviolet Spectrometer Instrument

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: These procedures are used in the event that one or more of the screw removal tasks of the experiment procedure cannot be accomplished.

PROCEDURE NO. 1 (for removing flex print)

(1) Release axial load from right angle driving head.

(2) Insert right angle driving head in tool box.

(3) Place power tool in tool box.

(4) Attach tether to sail clamp.

(5) Remove sail clamp and retain in hand.

(6) With other hand reposition sail (rotate sail 90 degrees to the right).

(7) Install sail clamp.

(8) Remove reel tether.

(9) Attach reel tether to flex print.

(10) Remove flex print cutter with tether attached.

(11) Cut flex print.

(12) Grip flex print with one hand and make second cut.

(13) Place flex print in general purpose container.

(14) Remove reel tether.

(15) Stow flex print cutter in tool box.

(16) Stow portable light.

(17) Astronaut abandons experiment and moves outboard.

PROCEDURE NO. 2 (For eye block connector and/or balance weight)

(1) Insert driving tool in tool box.

(2) Install screw head removal tool on power tool.

(3) If both eye block connector screws extracted, proceed to Step (6).

(4) Remove screw head.

(5) Repeat Steps (3) and (4) as required.

(6) If both screws retaining the balance weight extracted, return to Step (36) of experiment procedure. Position screw head removal tool over screw.

(7) Remove screw head.

(8) Repeat Steps (6) and (7) as required.

(9) Remove screw head removal tool, and place in box.

(10) Place power tool in tool box.

(11) Remove pry bar with tether attached from tool box.

(12) While holding balance weight with one hand, pry weight off screw shanks with pry bar.

(13) Place balance weight in general purpose container.

(14) Pry eye block connector off of screw shanks.

(15) Place pry bar in tool box.

(16) Remove cutter with tether attached from tool box.

(17) With other hand, cut wire bundle close to side of experiment package.

(18) Stow connector block in general purpose container.

(19) With cutter tool, push short end of wire bundle into experiment box.

(20) Place cutter in tool box.

(21) Attach reel tether to bolt cutter.

(22) Remove bolt cutter from tool box.

(23) Position bolt cutter over first screw [Step (4)].

(24) Cut first screw.

(25) Repeat Steps (24) and (25) as required.

(26) Place bolt cutter in tool box.

(27) Remove reel tether.

(28) Remove power tool from tool box.

(29) Insert screw head removal tool in power tool.

(30) Position screw head removal tool over first stud screw. [Step (4)]

(31) Remove stub screw.

(32) Repeat Steps (30) and (31) as required.

(33) Place screw head removal tool in tool box.

(34) Place power tool in tool box.

(35) Return to experiment procedure Step (42).

PROCEDURE NO. 3 (For Decoder Mounting Screws)

(1) Stow driving tool in tool box.

(2) Install screw head removal tool on power tool.

(3) Position power tool over unextracted screw.

(4) Remove screw head.

(5) Repeat Steps (3) and (4) as required.

(6) Return to Step (71) of experiment procedure.

PROCEDURE NO. 4 (For Rear Instrument Mounting Screws)

(1) Release right angle tool axial load.

(2) Place right angle tool in tool box.

(3) Place power tool in tool box.

(4) Attach reel tether to flex print.

(5) Remove flex print cutter with tether attached.

(6) Grip flex print with one hand and make second cut.

(7) Place flex print cutter in tool box.

(8) Place flex print in container.

(9) Remove reel tether.

(10) Close container.

(11) Stow mobile light

(12) Abandon experiment and astronaut moves to outboard position.

6.3.6.5 Retrieval of Ames Emissivity Plate

MISSION(S) 1

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To remove the Ames emissivity plate for returning to earth for post-flight analysis. This plate is of interest since its initial purpose was to measure the emissivity effects of celestial radiation of various surfaces. The last telemetry data available were obtained after 3,000 equivalent sun hours. With no further telemetry data available, the change in the emissivity properties cannot be accurately predicted. A data point obtained upon retrieval of the sensors would determine the long term space variation. Ground analysis of the Ames experiment sensors would add significantly to earlier predicted data concerning long term variation of polymeric materials exposed to space environments.

OBJECT DESCRIPTION: In general the plate is approximately 7.5 inches by 6 inches by 1/2 inch thick. A front view of the plate is shown in Fig. 6-3 and a rear view is shown in Fig. 6-4. The plate is mounted to the outside panel of compartment No. 5 of the wheel. The plate is attached to the wheel surface with eight NAS1218-06C8 screws with plastic washers. There are plastic standoff washers on the backside of the plate which holds the plate about 3/8 inch from the wheel surface. The standoffs are secured and will stay in place when the attachment screws are removed. Wiring runs from each sensor as shown in Fig. 6-4 and are secured very close on the inside of the compartment wall by a wire clamp. The wire bundle consists of approximately 15 wires; it is between 1/4 and 3/8 inch in diameter.

REMOVAL PROCEDURE:

(1) Orient and lock wheel with Ames panel in line of sight with astronaut.

(2) Astronaut moves inboard.

(3) Attach reel tether to protective cover.

(4) Remove protective cover.

(5) Install protective cover over emissivity plate.

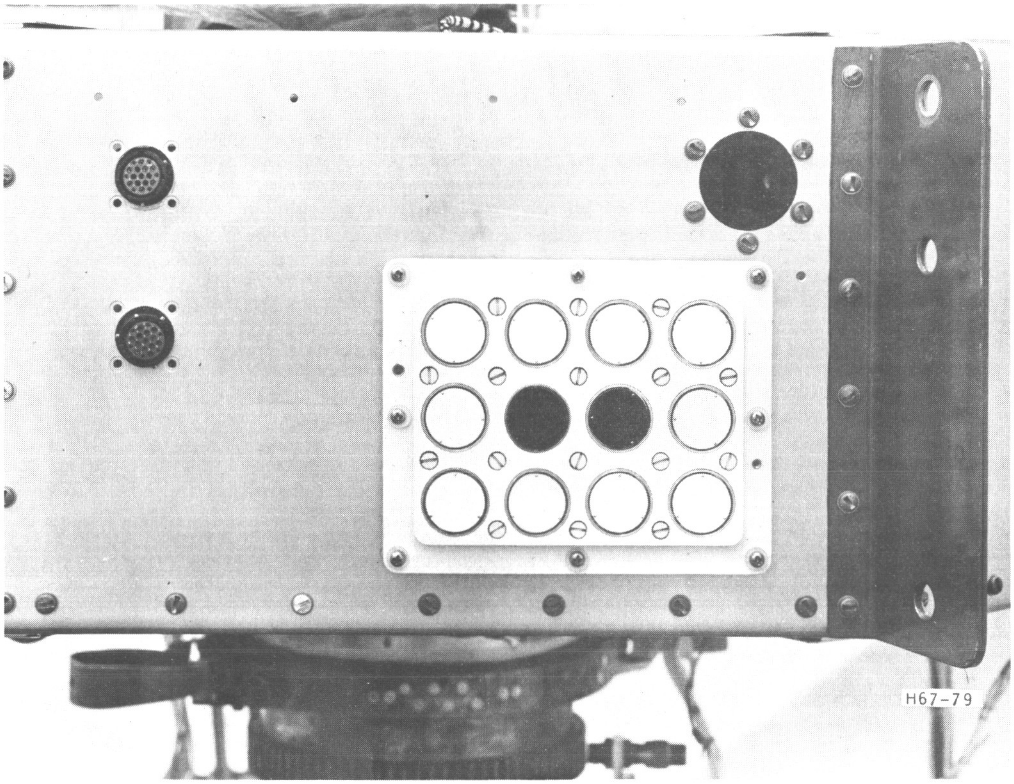


Fig. 6-3 Ames Emissivity Detector Plate - Front Surface

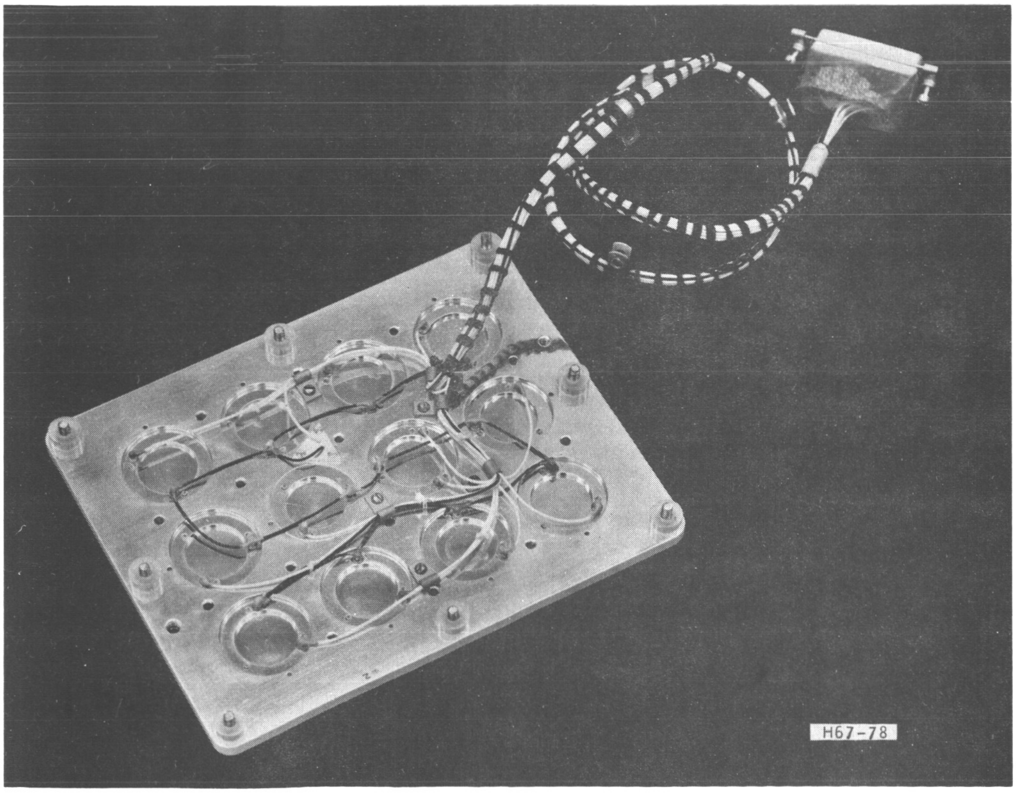


Fig. 6-4 Ames Emissivity Detector Plate - Back Surface

(6) Install cover screws (wing screws).

(7) Remove reel tether.

(8) Remove power tool from tool box.

(9) Install driving tool.

(10) Position power tool on first screw.

(11) Disengage screw from wheel. NOTE: Screw remains in plate. If screw fails to extract, proceed to Step (12).

(12) Repeat operation for 8 screws.

(13) Stow driving tool. If any screws fail to extract, use alternate procedure. NOTE: Return from alternate procedure.

(14) Stow power tool.

(15) Attach reel tether to cover plate.

(16) Move further inboard for cutting wire bundle.

(17) Grip handle of protective cover and pull emissivity plate away from wheel to expose wire harness.

(18) Orient portable light for cutting wire harness.

(19) Remove wire cutter from tool box (tether attached).

(20) Cut wire harness.

(21) Place cutter with tether attached in tool box.

(22) Open container.

(23) Place emissivity experiment package in container..

(24) Remove reel tether.

(25) Close container.

(26) Place portable light in stowed position.

(27) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Protective cover with handle for emissivity plate
- High torque driving tool
- Special storage container for emissivity plate

POTENTIAL PROBLEM AREAS: Possible difficulty in moving emissivity plate sufficiently to expose wire bundle for cutting due to absence of slack in wire bundle.

ALTERNATE: Retrieval of Ames Emissivity Plate

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: This procedure is used in the event that any screw head is unserviceable, or the screw cannot be removed.

PROCEDURE:

(1) Install screw head removal tool on power tool.

(2) Position power tool over unextracted screw.

(3) Remove screw head.

(4) Repeat Steps (2) and (3) as required.

(5) Stow screw head removal tool in tool box.

(6) Return to Step (14) of experiment procedure.

POTENTIAL PROBLEM AREAS: Emissivity plate may be difficult to pull off screw shanks.

6.3.6.6 Retrieval of University of Minnesota Zodiacal Light Telescopes

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To remove the University of Minnesota zodiacal light telescope assembly for return to earth for post-flight analysis of the optics. Post-flight analysis of the optics of the zodiacal light telescopes will aid in predicting and improving the operation of optical components in future space instrumentation systems. Future, post-flight analysis of the "satellite white" paint which was used for thermal protection and insulation can be compared with the original paint to determine changes in the paint characteristics due to long term exposure to space environment. Post-flight analysis will reveal information concerning space environmental effects on the optical systems with respect to:

- Surface damage by micrometeorites and sputtering
- Browning or yellowing discolorations which will decrease transmissivity as some function of wavelength
- Changes or acquisition of luminescence and fluorescence properties
- Shifts in index of refraction
- New or enhanced absorption bands
- Devitrification which crystallographically and physically alters glass nonhomogeneous and increases absorptivity
- Contamination due to sputtering and outgassing of other materials on the spacecraft and photopolymerization of condensed films

Comparative information can be gained between this experiment and the HCO instrument experiment, since HCO is located in the sail structure that points at the sun during orbit daylight, and the U. of Minn. telescopes are located in the spinning wheel section.

OBJECT DESCRIPTION: A front oblique view of the University of Minnesota instrument is shown in Fig. 6-5. The instrument is installed in wheel compartment No. 3, with four telescopes protruding through the side panel experiment. The telescopes to be removed are in the rim panel and are installed with five NAS1217-4C-6 (Allen head) screws and AN960-C-146 washers. Immediately behind the mounting plate of the telescope assembly is a layer of foil and a set of washers (2) around each attachment screw. The telescope and rim panel interface is as depicted in Fig. 6-6. The telescope assembly will weigh about 4 pounds and is approximately 12 by 12 by 3 inches.

PROCEDURE:

(1) Orient and lock wheel.

(2) Astronaut moves inboard.

(3) Attach reel tether to lens protective cover.

(4) Remove protective cover from storage container.

(5) Attach protective cover to four lens openings with clip behind foil layer.

(6) Remove power tool from tool box.

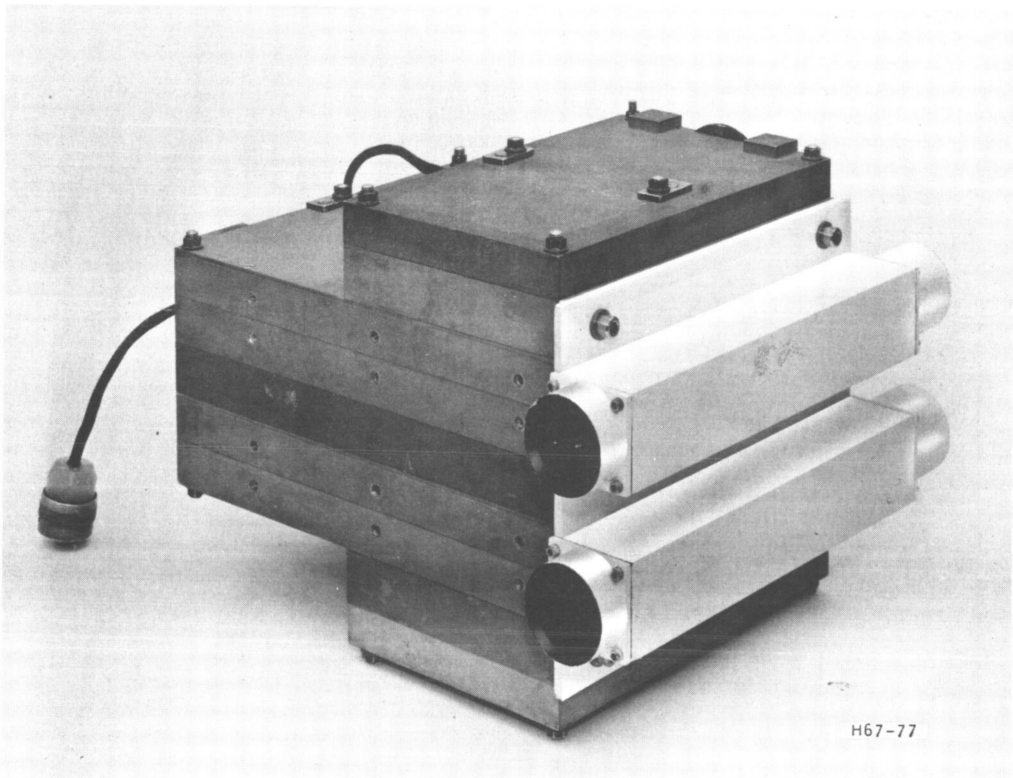


Fig. 6-5 University of Minnesota, Experiment - Oblique View

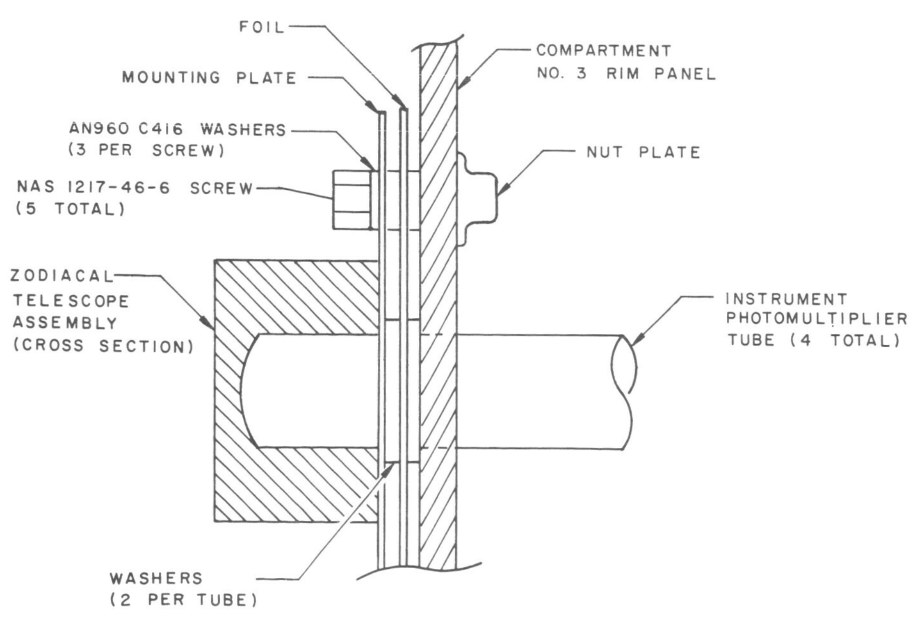


Fig. 6-6 Mounting Interface Diagram

(7) Attach driving tool to power tool.

(8) Position driving tool over first screw.

(9) Remove first screw. If screw fails to extract, proceed to Step (11).

(10) Place screw with washer if attached in general purpose container.

(11) Perform Steps (8), (9), and (10) for five screws. If any screw fails to extract, proceed to alternate procedure.

(12) Place driving tool in tool box.

(13) Place power tool in tool box. NOTE: Return from alternate procedure.

(14) Open container.

(15) Pull telescope assembly and foil layer out radially from satellite to clear photomultiplier tubes inserted in telescope assembly openings in the back.

(16) Place telescope assembly with foil layer into container.

(17) Remove reel tether.

(18) Close container.

(19) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Lenses protective covers (4) with foil retention clips
- Driving tool (Allen head)
- Inert gas storage container

POTENTIAL PROBLEM AREAS:

(1) Allen head screws may be difficult to remove

(2) Additional washers will be difficult to handle and may be lost. (Loss of the extra washers will not be critical.)

(3) Foil layer may be difficult to handle and may tear and/or be lost. (Loss of the foil will not be critical.)

ALTERNATE: Retrieval of University of Minnesota Zodiacal Light Telescopes

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: This procedure is used in the event that one or more of the mounting screws cannot be removed during the experiment removal procedure.

PROCEDURE:

(1) Stow driving tool.

(2) Install screw head removal tool on power tool.

(3) Position power tool over screw head.

(4) Remove screw head.

(5) Repeat Steps (3) and (4) as required.

(6) Stow screw head removal tool in tool box.

(7) Stow power tool in tool box.

(8) Return to Step (14) of experiment procedure.

6.3.6.7 Retrieval of GSFC Ultraviolet Spectrometer Azimuth Indexer

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To remove the GSFC ultraviolet spectrometer azimuth indexer for return to earth for post-flight material analysis. The GSFC azimuth indexer mechanism is a conventional bearing operating in one atmosphere of helium. Ground simulation cannot completely reproduce the integrated affect of the low gravity and high vacuum operation for a period of years on the mechanism used. Post-flight analysis of the GSFC-UV azimuth indexer will reveal design information with respect to the operating efficiency of mechanisms in a space environment vs ground ambient environment. Examination will also yield information concerning bearing and friction wear.

OBJECT DESCRIPTION: Two pictures of the Azimuth Indexer are shown in Figs. 6-7 and 6-8. The unit is an irregular shape weighing about 5 pounds and is attached to the underside of the GSFC instrument by three 6/32 diameter slot head screws below the bottom panel of wheel compartment No. 2. During installation, the screw threads were engaged about 5/16 inch, and were set with Loctite Grade E. Accessibility to these screws is from the underside of the OSO satellite. There is a pig-tail connector to the azimuth indexer which is clearly shown in Fig. 6-8. The wire bundle is about 1/2 inch in diameter and contains 32 wires, several of which are shielded wires. The connector is a Deutsch snap-on type.

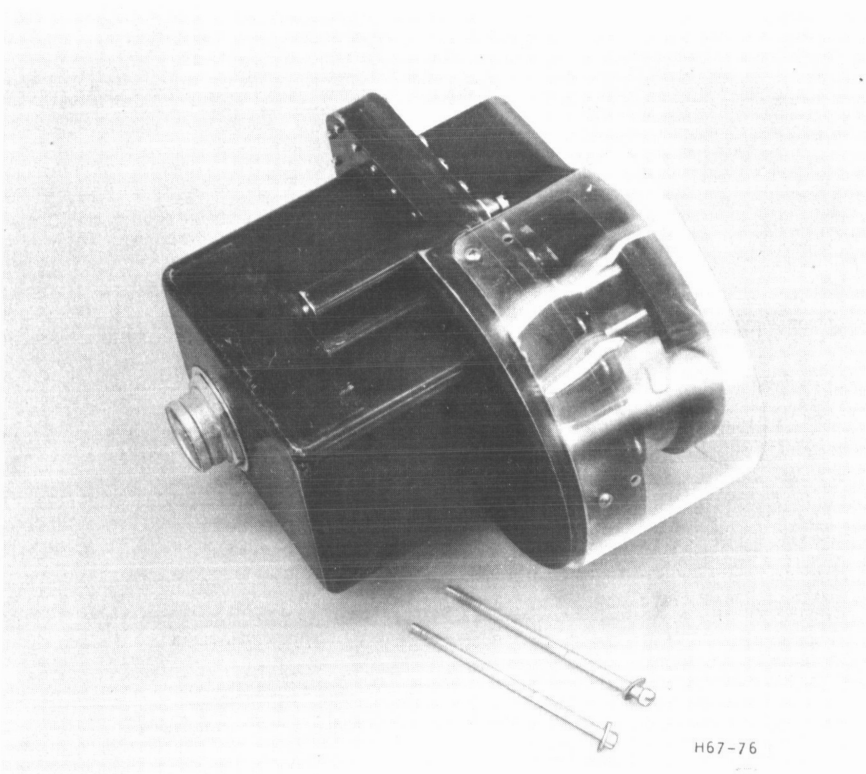


Fig. 6-7 GSFC Azimuth Indexer - Top View

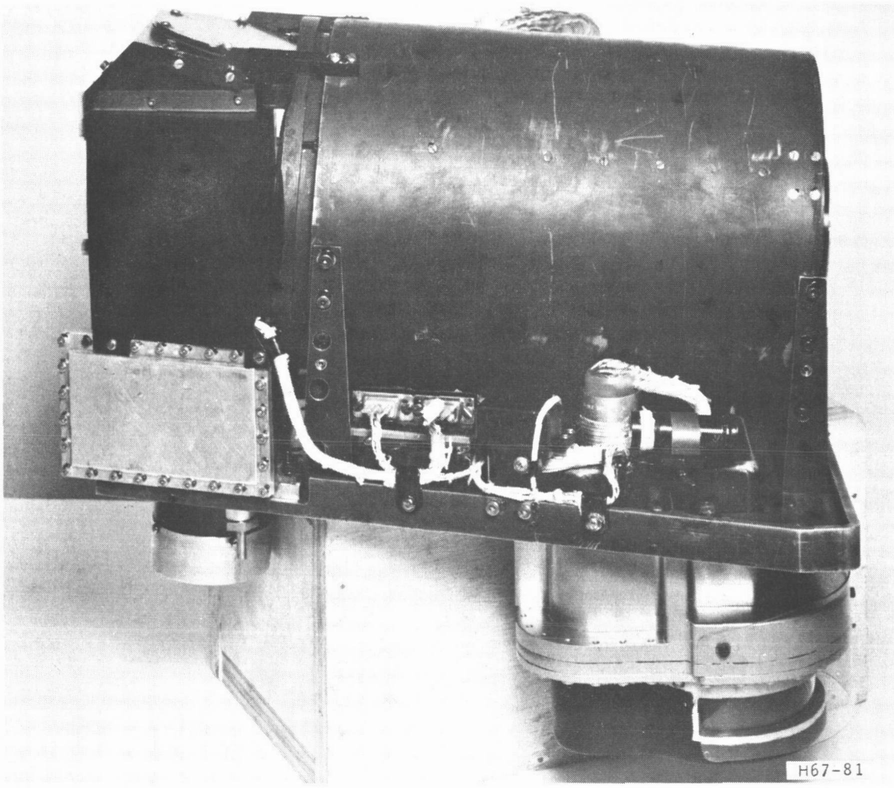


Fig. 6-8 GSFC Azimuth Indexer - Side View

REMOVAL PROCEDURE:

(1) Astronaut, below wheel and antennas, positions and locks wheel.

(2) Astronaut moves up until head is slightly below lower surface of wheel.

(3) Position lights.

(4) Remove power tool from tool box.

(5) Insert driving tool.

(6) Position power screw driver on first screw.

(7) Remove screw. If any screw fails to extract, proceed to next screw.

(8) Place screw with washer attached in general purpose container.

(9) Repeat Steps (6), (7) and (8) for second and third screws.

(10) Stow driving tool in tool box. If any screws fail to extract, go to alternate procedure.

(11) Stow power tool in tool box. NOTE: Return from alternate procedure.

(12) Attach reel tether to experiment package.

(13) Pull experiment package free from wheel.

(14) Remove cutter (tether attached) from tool box.

(15) Grip azimuth indexer with one hand, with other hand cut wire harness.

(16) Place azimuth indexer in special container.

(17) Remove reel tether.

(18) Close container.

(19) Stow cutter in tool box.

(20) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Driving tool (slot head)
- Long blade wire cutter with tether
- Inert gas storage container

POTENTIAL PROBLEM AREAS: Slot head screws may be difficult to remove.

ALTERNATE: Alternate Removal of GSFC-UV Azimuth Indexer

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: This procedure is used in the event that one or more of the mounting screw heads is rendered unserviceable or cannot be removed during the experiment removal procedure.

PROCEDURE:

(1) Install screw head removal tool on power tool.

(2) Position power tool over screw which failed to extract.

(3) Remove screw head.

(4) Repeat Steps (2) and (3) as required.

(5) Stow screw head removal tool in tool box.

(6) Stow power tool in tool box.

(7) Return to step 12 of experiment procedure.

6.3.6.8 Retrieval of University of New Mexico High Energy Gamma-Ray Telescope Foil Covers

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To remove the University of New Mexico gamma-ray telescope foil covers for return to earth for post-flight material analysis with regard to micro meteroid bombardment after long term exposure to space environment.

OBJECT DESCRIPTION: A front view of the U. of New Mex. instrument is shown in Fig. 6-9. The instrument is installed in wheel compartment No. 9, with the telescope protruding through the wheel rim panel. The aluminum foils cover a plastic scintillator; they are held in place by a cover plate with eleven screws. The screws are located around a 6-3/8 inch diameter circle. There are three foils separated from the scintillator by 30 mils of silicon tape. The screws are Allen head, and they were installed with Loctite Grade E into threaded holes in the instrument housing.

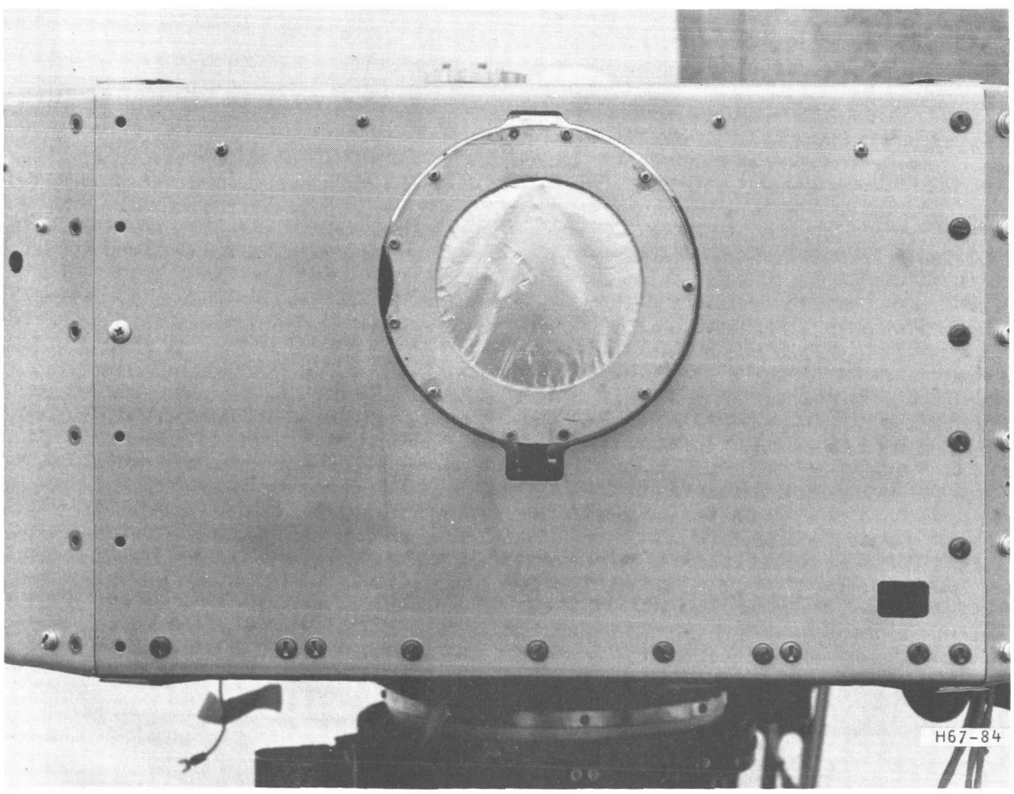


Fig. 6-9 University of New Mexico Experiment

REMOVAL PROCEDURE:

(1) Orient and lock wheel.

(2) Astronaut moves inboard.

(3) Attach reel tether to foil protective cover.

(4) Attach protective cover to flange.

(5) Remove power tool from tool box.

(6) Insert driving tool in power tool.

(7) Position driving tool over first screw.

(8) Remove first screw. If screw fails to extract, proceed to Step (10).

(9) Place screw in general purpose container.

(10) Repeat Steps (7), (8), and (9) ten times. If any screws fail to extract, use alternate procedure.

(11) Place driving tool in tool box.

(12) Place power tool in tool box. NOTE: Return from alternate procedure.

(13) Open container.

(14) Remove foil and flange.

(15) Place foil and flange in container.

(16) Remove reel tether.

(17) Close container.

(18) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Driving tool (Allen head)
- Protective cover plate
- Inert gas storage container (7 inch diameter by 1 inch)

POTENTIAL PROBLEM AREAS:

(1) Allen head screws may be difficult to remove.

(2) Foils will be difficult to handle and easily damaged when attaching protective cover.

ALTERNATE: Retrieval of University of New Mexico Foil Filters

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: This procedure is used in the event that one or more of the screw removal tasks of the experiment procedure cannot be accomplished.

PROCEDURE:

(1) Stow driving tool in tool box.

(2) Install screw removal head on power tool.

(3) Position tool over screw head.

(4) Remove screw head.

(5) Repeat Steps (3) and (4) as required.

(6) Stow screw head removal tool in tool box.

(7) Stow power tool in tool box.

(8) Return to Step (13) of experiment procedure.

6.3.6.9 EVA Documentation Photography

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Primary (Mission 1 only)

PURPOSE AND OBJECTIVE: To conduct documentary photography of EVA while conducting the useful work tasks which will establish a photographic record of the EVA operations.

Documentary photography of EVA operation during the Gemini program has proved the capability of obtaining excellent pictorial records of astronauts conducting EVA, which are useful in post-flight analysis and correlation with preflight training.

OBJECT DESCRIPTION: The EVA astronaut will conduct both transfer operations and useful work while fixed to a work platform. EVA activity will be monitored by time-sequence colored photography.

PROCEDURE:

(1) The IVA astronaut will monitor and take pictures of the EVA astronaut from the CSM while the EVA astronaut transfers from the CSM to the work platform, deploys the platform, fixes himself to the work platform, and returns to the CSM upon completion of experiments.

(2) Time-sequenced pictures will be taken while the EVA astronaut is conducting useful work.

The EVA astronaut will also operate the stationary camera. His tasks will be as follows:

a. Position EVA monitoring camera.

b. Actuate camera for time-sequenced pictures at start of each experiment.

c. Stop camera at completion of each experiment.

d. Reload camera two times.

e. Stow exposed film three times.

SPECIAL TOOLS AND EQUIPMENT:

- Two Maurer 16 mm sequential cameras, Model 308, with standard C mount lens and colored films

- Mounting apparatus at work site for camera with electronics for remote control

POTENTIAL PROBLEMS: Obtaining full film coverage of all useful work operations.

6.3.6.10 Experiment Container Stowage Preparation

MISSION(S) 1

EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To prepare the experiment containers for stowage in the Command Module and subsequent return to earth. The results to be obtained by accomplishing this mission support operation will be the protection and preservation of the experiments removed from the OSO during their return to earth by pressurizing the experiment containers with inert gas.

OBJECT DESCRIPTION: Two types of containers are utilized. One will be a general purpose container for the collection of screws, washers, connectors, pigtails, etc. This container will be a simple, closed container. The second type is a special container(s) to package the various experiments being returned for post-flight analysis.

PROCEDURE:

(1) All containers should be closed. Remove gas line cap (tethered to container).

(2) Astronaut attaches inert gas supply line to inert atmosphere experiment container(s).

(3) Astronaut opens valve on inert gas pressure line.

(4) Read pressure indicator on inert gas experiment container.

(5) Close inert gas supply valve.

(6) Remove gas supply line from experiment container.

(7) Install experiment container gas line cap.

SPECIAL TOOLS AND EQUIPMENT:

- Inert atmosphere experiment container(s) with gas line cap attached.
- Inert atmosphere low pressure gas supply.
- General purpose vacuum container with gas line cap.

6.3.7 Refurbishment

There is only one refurbishment experiment proposed for Mission 1, which is to replenish the pitch gas supply. This experiment is proposed to serve as a practice operation for Missions 2 and 3, where the task would be conducted on operational OSO satellites.

6.3.7.1 Replenish Pitch Gas Supply

MISSION(S) 1

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To replenish a depleted gas system of the OSO while the satellite is in orbit. Replenishment of the pitch gas system on Mission 1 will serve as a practice operation for Missions 2 and 3 to prove out the equipment and techniques.

OBJECT DESCRIPTION: The spin and pitch gas control systems are illustrated in Fig. 6-10. The check valve for replenishing the pitch gas supply system is located in the lower right hand corner of the sail structure. It is readily accessible from the right side of the sail structure. (BBRC Drawing E8011 - Upper Section Assembly) The check valve (BBRC Drawing C8383 - Check Valve) has a threaded nipple to which the fill supply hose will be attached. This nipple is protected by a cap (BBRC Drawing B7774 - Cap - Pressure Seal, Modified). The pitch gas system contains 4.4 pounds of nitrogen stored in a titanium bottle at 3000 ± 100 psig. At this pressure, the safety factor with respect to ultimate strength is 2.15. The pitch gas system operates at a nominal pressure of 30 psig.

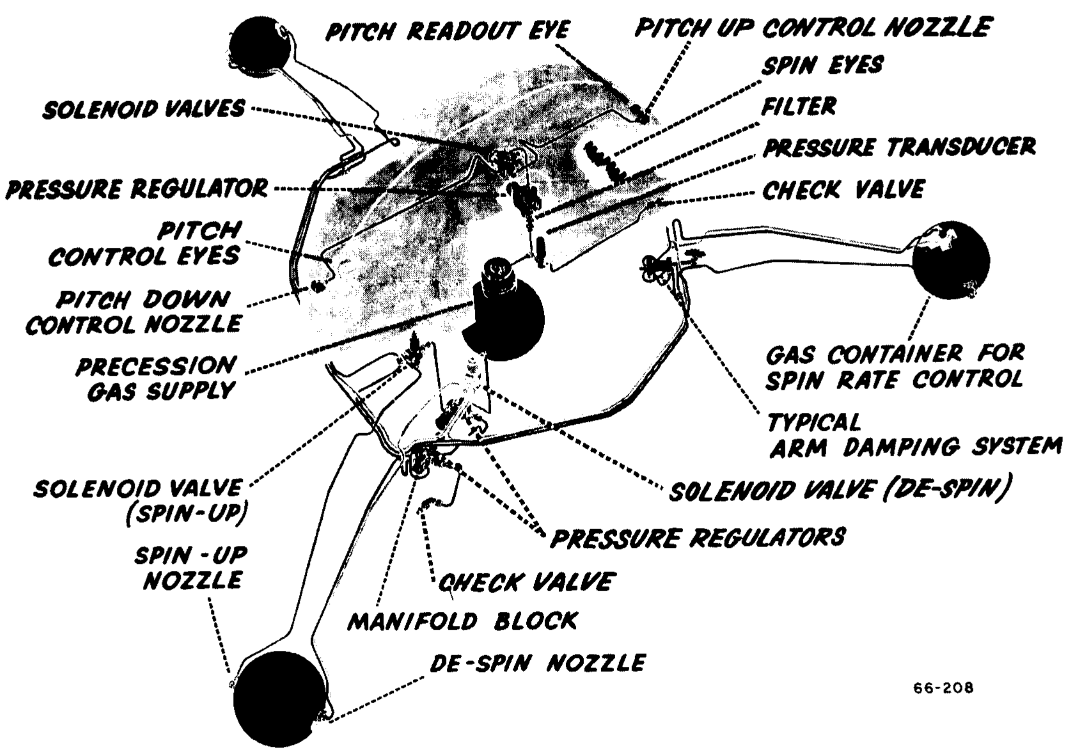


Fig. 6-10 OSO II - Gas Control Systems

CONSTRAINTS: The constraints affecting this task are:

For EVA astronaut

- Satellite commanded off
- Wheel umbilical power bus removed
- Sail section locked to wheel
- Light sources operating

For IVA astronaut

- Work platform stowed prior to commencing actual gas replenishment
- All EVA work tasks completed or abandoned
- Filling assemblies attached to satellite gas fill line by EVA astronaut
- EVA astronaut in CM
- CM pressurized
- Boom umbilical lines stowed

PROCEDURE:

For EVA astronaut

(1) Orient and lock wheel with sail pitch gas filling line in position for work.

(2) Astronaut moves inboard.

(3) Attach reel tether to check valve fitting tool.

(4) Remove check valve fitting tool from tool box.

(5) Position fitting tool over check valve fitting.

(6) Attach fitting tool to sail structure.

(7) Remove reel tether.

(8) Remove power tool from tool box.

(9) Attach pitch gas cap removal tool to power tool.

(10) Position removal tool over pitch gas line cap.

(11) Remove pitch gas line cap.

(12) Place cap in general purpose container.

(13) Place cap removal tool in tool box.

(14) Place power tool in tool box.

(15) Attach reel tether to quick disconnect coupling.

(16) Position disconnect coupling on pitch gas line and hand thread.

(17) Remove reel tether.

(18) Attach reel tether to ratchet tool.

(19) Remove ratchet tool from tool box.

(20) Position ratchet tool over quick disconnect.

(21) Tighten quick disconnect to gas line.

(22) Place ratchet tool in tool box.

(23) Remove reel tether.

(24) Attach reel tether to check valve fitting tool.

(25) Remove check valve fitting tool.

(26) Place fitting tool in tool box.

(27) Remove reel tether.

(28) Remove gas supply line from stowed position.

(29) Using quick disconnect fitting, attach pitch gas supply line to sail quick disconnect fitting.

(30) Attach reel tether to sail lock.

(31) Remove sail lock short tether from sail structure.

(32) Remove sail lock from sail.

(33) Place sail lock in tool box.

(34) Remove reel tether.

(35) Astronaut moves outboard.

NOTE: Mission Operation Task 6.3.8 - Return of EVA astronaut and Experiment to Command Module - must be performed prior to completing this experiment.

For IVA astronaut

(1) Unstow command controller.

(2) Attach controller umbilical power line to CM.

(3) Energize controller (stand by).

(4) Aim controller antenna through window.

(5) Depress fill command button.

(6) Depress pressure read indicator.

(7) When pressure is at required value, depress pressure off button.

(8) Depress disconnect button.

(9) Inspect pressure lines and visually verify disconnect.

(10) Remove controller umbilical power line from CM

(11) Stow controller.

HAZARD CONDITIONS:

- Normal edges and corners on sheet metal and machined surfaces
- Arms with high pressure spheres
- Operating with high pressure gas system

ACCESSIBILITY: Good; the pitch gas check valve is readily accessible on the right hand side of the sail.

SPECIAL TOOLS AND EQUIPMENT:

- Drive tool for removing and containing cap
- Remotely operated high pressure nitrogen gas supply
- Remotely operated attach fitting
- Power tool ratchet handle
- Check valve fitting tool

- Quick disconnect coupling
- Hand held command controller
- CM umbilical power connector

OTHER SUPPORT REQUIREMENTS:

- EVA and IVA astronaut
- EVA communications link with CM
- Procedural transmission from CM to EVA astronaut
- Adjustable work platform with astronaut fixity
- Artificial illumination including portable light
- Remote wheel positioner and lock
- Device for locking sail
- Power tool for driving adaptive tools
- Reel tether with clamp
- Tool box
- General purpose (GP) storage container
- Short tether

GROUND SUPPORT REQUIREMENTS: None

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with OSO and gas supply mockup, no suit
- Familiarization with OSO, gas supply and work platform mockup; suit pressurized to 3.7 psig, environment 1 g
- Neutral buoyancy simulation for time line evaluation
- Use of EVA tools

POTENTIAL PROBLEM AREAS: Operating with the high pressure gas system

6.3.8 Return of EVA Astronaut and Experiments to Command Module

MISSION(S) 1, 2, 3

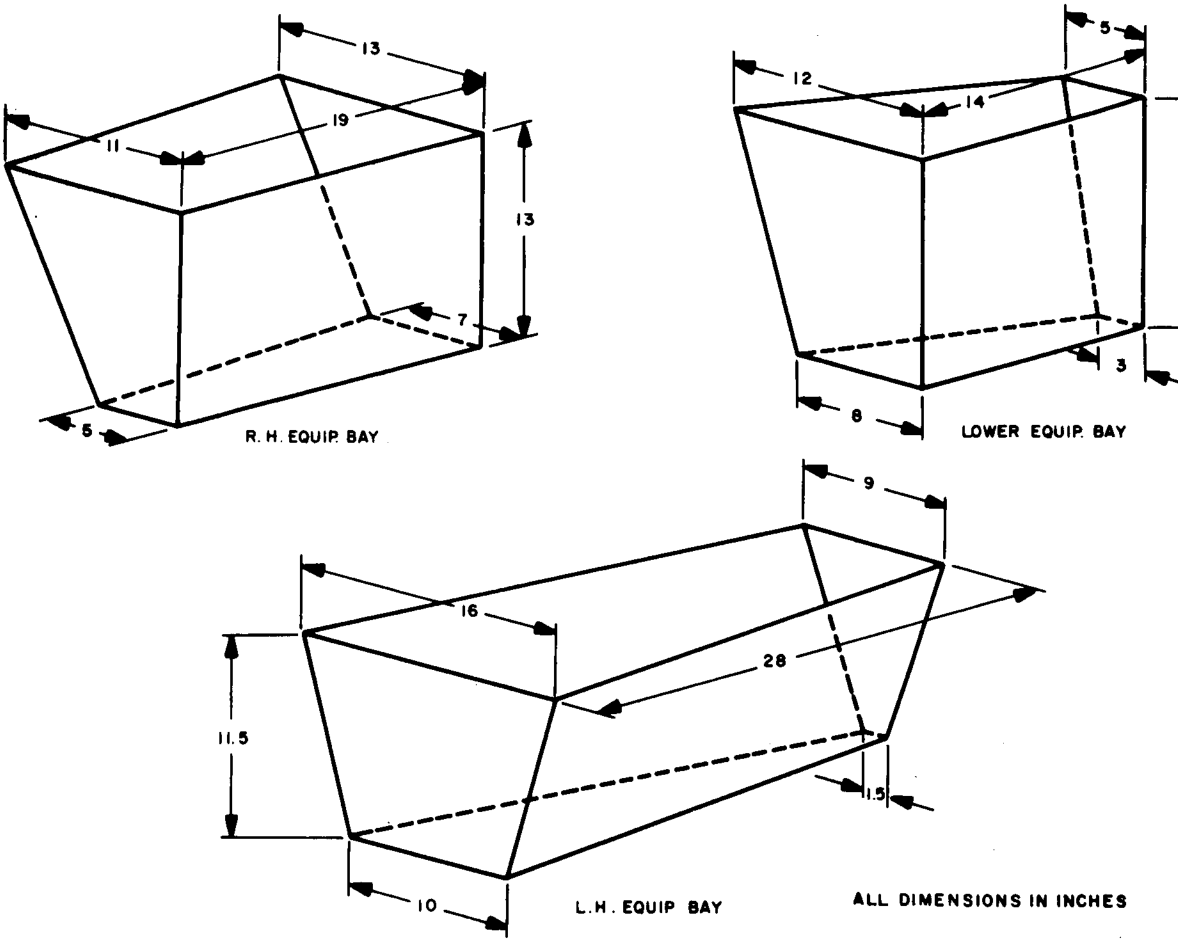
EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To stow experiment containers and equipment in the Command Module and return the EVA astronaut to the CM in preparation for return to earth.

OBJECT DESCRIPTION: Storage containers will be provided for the return of instrumentation equipment, cameras and exposed film and experiments which have been retrieved from the OSO satellite. A listing of the items to be returned is presented in Table 6-3, giving an approximate description of each item with respect to height (H), width (W), length (L), and weight (wt). Possible storage areas in the Apollo Command Module are shown in Fig. 6-11. A detail analysis and investigation must be completed to determine the optimum size(s) of storage container(s) which must package the selected items for retrieval and still be compatible with available CM storage space.

Table 6-3
MISSION 1 RETRIEVAL ITEMS

Item	H (in.)	W (in.)	L (in.)	wt (lb)
Directional spectrometer	6	x 6	x 12	15
70 mm Maurer camera	5-1/2	7-1/2	1-3/4	5
Film	5-1/2	x 1 dia	x 10	5
16 mm Maurer Mod 308 camera	3-1/2	1-3/4	6	2
Film	3-1/2	12	5	10
Dosimeter	6 dia	x 4 dia		1
NRL occulting disk	2	1	4	
Control sensor assembly	4	4	4	1
Right hand solar panel	22	22	2	10
HCO instrument	10	6	40	50
R.P.T. assembly	5	4	8	2
Decoder	3	x 7 dia		10
Ames plate	6	1	8	2
U. of Minn. telescopes	12	3	12	3
U. of N. Mex. foil filters	1	x 7 dia		1
GSFC-UV azimuth indexer	8	6	8	15
TOTAL				132



Area	Volume (cu. ft.)
Food Compartment (Lower Equipment Bay)	1.0
Food Compartment (L. H. Equipment Bay)	1.7
Food Compartment (R. H. Equipment Bay)	0.9
LIOH Cannisters Area	4.5
Isleway (under center couch)	3.0
	11.1

Fig. 6-11 Possible CM Storage Areas (Ref. 20)

CONTTRAINTS:

(1) All stored items must be adequately secured to withstand the Apollo Command Module re-entry loads.

(2) The storage containers must be adequately sealed so as not to outgas into the CM, or receive contaminants into the containers.

(3) The storage containers must be compatible with the available CM storage spaces.

(4) EVA astronaut is in outboard position on work platform.

(5) EVA work tasks and experiments must be either completed or abandoned.

PROCEDURE:

(1) Translate platform to wheel bottom position.

(2) Astronaut moves inboard.

(3) Release capture mechanism OSO spin brake.

(4) Test OSO spin freedom by pushing wheel in a clockwise direction.

(5) Astronaut moves outboard.

(6) Translate platform to down position.

(7) Pivot platform to position parallel to axis of boom.

(8) Astronaut removes waist restraint clips.

(9) Astronaut releases tether from platform clip.

(10) Astronaut disengage feet from foot restraints.

(11) Astronaut leaves platform, and moves along CWP toward CSM.

(12) Astronaut attaches his tether to CWP structure to provide restraint.

(13) Position and adjust equipment transfer tethers.

(14) Attach GP and experiment containers to transfer tethers.

(15) Release first container from CWP fastening brackets.

(16) Astronaut hand walks along egress/ingress structures to forward hatch with container.

(17) EVA astronaut transfers container to IVA astronaut inside CM.

(18) EVA astronaut releases container transfer tether.

(19) Repeat Steps (15), (16), (17), and (18) for remaining containers.

(20) IVA astronaut stows containers in CM.

(21) EVA astronaut secures work platform in stowed position.

(22) Disconnect CWP power umbilical.

(23) EVA astronaut performs ingress to CM.

(24) Secure CM forward hatch.

HAZARD CONDITIONS: None

ACCESSIBILITY: Good

SPECIAL TOOLS AND EQUIPMENT:

- Egress/ingress structure and adjustable work platform with astronaut fixity
- Equipment transfer tethers
- Electrical umbilical
- Artificial illumination

OTHER SUPPORT REQUIREMENTS:

- EVA communications link with CSM
- Procedural transmission from CSM to EVA astronaut
- Astronaut EVA equipment (tether, lifesupport equipment etc.)

GROUND SUPPORT REQUIREMENTS: None

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with CSM/forward hatch/tethers/work platform mockup; no suit, 1 g environment
- Neutral buoyancy EVA simulation for time line evaluation

POTENTIAL PROBLEM AREAS: None

6.3.9 OSO Release and CWP Jettison

MISSION(S) 1, 2, 3

EXPERIMENT PRIORITY Mission Support Operation

PURPOSE AND OBJECTIVE: To release the OSO and to jettison the CWP to prepare the CSM for return to earth.

OBJECT DESCRIPTION: The OSO release mechanism will be an integral part of the capture work platform attachment head. The release mechanism will be operated remotely while releasing the OSO. The docking collar on the CWP will be similar to the LEM docking collar.

CONSTRAINTS:

(1) Experiments must have been completed or abandoned.

(2) Experiment containers must have been stowed in CM.

(3) Work platform must be in stowed position.

(4) EVA astronaut must be inside the CM.

(5) CM must be repressurized.

(6) CSM spacecraft must be in proper attitude.

(7) Care must be taken not to contaminate the OSO with the RCS thrusters during the backing away operation.

PROCEDURE:

(1) Spin OSO up to approximately 6 rpm.

(2) Release CWP attachment head from OSO.

(3) Fire RCS thrusters to slowly back CSM away from OSO to a safe distance.

(4) Release the CWP docking collar and fire RCS thrusters to back the CSM away from the CWP to a safe distance.

HAZARD CONDITIONS:

- Releasing the spinning OSO
- Releasing the CWP

ACCESSIBILITY: Not applicable.

SPECIAL TOOLS AND EQUIPMENT: CWP with release capability

OTHER SUPPORT EQUIPMENT: Apollo Command Service Module

GROUND SUPPORT REQUIREMENTS: Communications link between CSM and MCC.

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with operating procedure
- Docking and release practice on spacecraft docking simulator device similar to CSM/LEM operation

POTENTIAL PROBLEM AREAS: None

6.4 EXPECTED SIGNIFICANT RESULTS

The major expected significant results from Mission 1 are:

- Evaluation of orbit transfer and techniques for rendezvous with a non-cooperative satellite
- Extensive evaluation of capture and release techniques and hardware
- Extensive evaluation of EVA technology
- Determination of the affects of the space environment on:

  a. Transmission optical elements

  b. Reflection optical elements

  c. Solar cells

  d. Polymeric materials

e. Electromechanical devices

f. Electronic components

- Evaluation of unexplained failures in scientific instrumentation
- Evaluation of micrometeorite data unobtainable by other means
- Extensive EVA experience in performing useful work

6.5 INTEGRATED TIME LINE

The IVA and EVA time required to perform each task presented in Section 6.3 is summarized and integrated in a time line analysis for Mission 1 which is presented in Fig. 6-12

6.6 TOOLS AND EQUIPMENT

The special tool and equipment requirements to conduct the experiments for ESMRO Mission 1 have been summarized in Table 6-4. A commonality usage of these tools is presented in the Tool Usage Chart, Table 6-5.

Table 6-4
SPECIAL TOOLS AND EQUIPMENT FOR MISSION 1

Operation	Equipment
1. Post-capture photography	1. Still camera
2. Preexperiment preparation and radiation monitoring	1. Radiation monitor 2. Equipment transfer tether
3. Satellite centering and adhesive release	1. Adhesive heating umbilical line
4. Wheel power bus removal	1. Connector removal tool
5. Freedom and damage evaluation	
6. Occulting disk removal	1. Allen head screw driving tool 2. Rigid tether
7. Control sensor assembly removal	1. Screw driving tool 2. Protective lens cover
8. Right hand solar panel removal	1. Solar cell core drill 2. Solar panel core drill 3. Variable angle wedge with tether 4. Short tether
9. HCO instrument removal	1. Decoder screw driving tool 2. Flex print cutter with tether 3. Aperture protective cover 4. Ion trap protective cover

Table 6-4 (Cont.)

Operation	Equipment
9. HCO instrument removal	5. Screw driving tool 6. Right angle screw driving tool 7. HCO short tether with double clamps
10. Ames emissivity panel removal	1. Screw driving tool 2. Protective cover
11. U. of Minn. telescope removal	1. Screw driving tool 2. Protective lens covers
12. GSFC azimuth indexer removal	1. Screw driving tool
13. U. of N. Mex. foil removal	1. Foil protective cover with wing screws 2. Screw driving tool
14. Pitch gas supply refurbishment	1. Cap removal tool 2. Check valve fitting tool 3. Gas supply line 4. Remote filling and disconnect equipment
15. Experiment container stowage	1. Inert atmosphere gas supply source
16. Return of astronaut and experiments to CSM	1. Equipment transfer tether

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Table 6-5

TOOL USAGE CHART FOR MISSION 1

Description	Post-Capture Photography	Preexperiment Prep. and Radiation Mon.	Satellite Centering and Adhesive Release	Wheel Power Bus Removal	Freedom and Damage Evaluation	Occulting Disk Removal	Control Sun Sensor Assembly	Right Hand Solar Panel Removal	HCO Instrument Removal	Ames Emissivity Panel Removal	U of Minn Telescope Removal	GSFC Azimuth Indexer Removal	U of N Mex Foil Filter Removal	Pitch Gas Supply	Experiment Container Stowage	Astronaut and Experiment Return
Remote wheel positioning Lock	X		X	X	X	X	X	X	X	X	X	X	X	X	X	
Work platform	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
EVA communications link	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Flood lights	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Portable light								X	X	X						
Tool box			X	X	X	X	X	X	X	X	X	X	X	X		
Astronaut tether	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Elevation lock					X	X	X	X	X	X						
Sail lock					X	X	X	X	X	X	X		X			
Reel tether				X	X	X	X	X	X	X	X	X	X	X		
GP container						X	X	X	X	X		X		X	X	
Inert gas pressurized experiment container							X	X	X	X	X		X			
Vented container						X		X	X	X	X	X	X	X	X	
Time sequence camera				X	X	X	X	X	X	X	X	X	X	X		
Still camera power tool	X		X			X	X	X	X	X	X	X	X	X		
Power tool ratchet																
Screw head removal tool							X		X		X	X	X			
Pry bar with tether							X		X			X				
Wire bundle cutter with tether								X	X	X		X				
Bolt cutter with tether									X	X						

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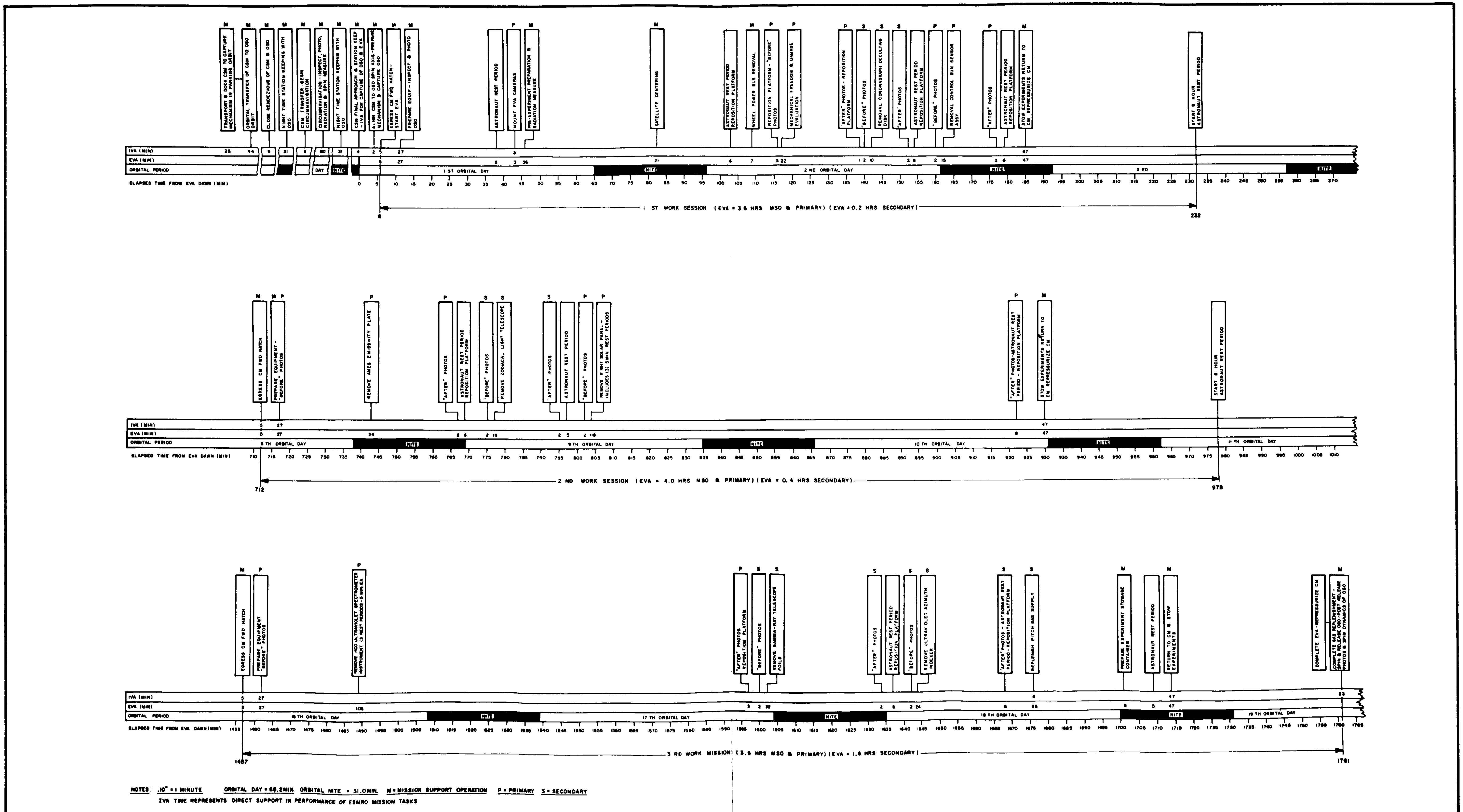


Fig. 6-12 Mission 1 Time Line Analysis

SECTION 7

MISSION 2 PROGRAM PLAN

Section 7
MISSION 2 PROGRAM PLAN

This section includes the details for the ESMRO Mission 2 program plan. This is the first major refurbishment mission and should be performed prior to ESMRO MIssion 3. It could be performed before or after the material retrieval mission (See ESMRO Mission 1, Section 6), but it is recommended that it be performed after Mission 1, since that mission will prove out the OSO capture techniques.

7.1 MISSION OBJECTIVE

The primary objective of Mission 2 is to rendezvous, capture, perform useful work, and release the target OSO. The useful work is to consist primarily of refurbishment of the target OSO to improve or extend its operation in orbit. Secondary objectives include evaluation of capture techniques, advancement of EVA technology, and release of the target OSO into an operational orbit.

7.2 MISSION CHARACTERISTICS

7.2.1 Time Frame

Mission 2 can be performed in the 1969, 1970 time frame.

7.2.2 Target OSO

The target OSO for Mission 2 is to be one that is partially or fully operational, or one that has a high probability of being reactivated; its extended operation should yield significant new scientific or technological data. The candidate OSO's that will probably be in this status for this time frame are the OSO F or OSO G. The objectives of this mission do not require that major modifications be made to the target OSO prior to its launch; therefore, either of the aforementioned candidates (or later OSO's) are eligible.

7.2.3 Orbital Conditions

The mission will be initiated with the CSM in a 370 kilometer (200 nautical mile) altitude parking orbit, at an inclination compatible with the OSO orbit. The CSM is to be launched so that the longitude of its ascending node is within ± 2 degrees of the target OSO; it should approach the OSO from the east.

The target OSO will be in an orbit that has the following nominal parameters:

- Circular orbit: 555 $\pm$ 92 km (300 $\pm$ 50 nm)
- Inclination: 33 $\pm$ 3 deg
- Period: 96 min

7.3 MISSION OPERATIONS

The mission operations consist of the following functional steps:

- Capture mechanism docking
- Rendezvous maneuvers
- Precapture inspection during station keeping
- Capture
- Post-capture inspection and preparation
- Material retrieval
- Refurbishment
- Stowage of materials
- Release and capture mechanism jettison
- Post-release inspection

Each of these functional steps includes tasks that are unique in the accomplishment of the mission. These tasks are discussed in detail in this section, and are itemized in Table 7-1. The level of detail description is intended to define the scope of the major tasks, and does not include details on general mission support operations. Also indicated in this table is the reference section number and a designation of the task priority. The priority designations (MSO, P, and S) are the same as those defined in Section 6.3.

Many of the mission support operation tasks are the same as those for Mission 1 and, therefore, the reference section number is in Section 6.3. Descriptions for these mission support operation tasks are not repeated for this mission plan, since they are available in Section 6.3.

Table 7-1
SUMMARY OF MISSION 2 OPERATION TASKS

Experiment Task	Reference Section No.	Priority
Capture mechanism docking	7.3.1	MSO
Rendezvous maneuvers	7.3.2	MSO
Precapture inspection during station keeping	7.3.3	
Determination of OSO radioactive levels	6.3.3.1	MSO
Determination of OSO dynamics	6.3.3.2	MSO
Documentation photography	6.3.3.3	MSO
Capture Operations	7.3.4	
Maneuvers and OSO capture	6.3.4.1	MSO
Documentation photography	6.3.3.3	MSO
Post-capture inspection and preparations	7.3.5	
Experiment preparation and radiation monitoring	6.3.5.1	MSO
OSO centering	6.3.5.2	MSO
OSO wheel power bus removal and umbilical attachment	7.3.5.3	MSO
Mechanical freedom and damage evaluation	6.3.5.4	P
Documentation observations and photography	7.3.5.5	MSO
Material retrieval	7.3.6	S
Refurbishment	7.3.7	
Replenishment of pitch gas supply	7.3.7.1	P
Replenishment of spin gas supply	7.3.7.2	P
Addition of new battery power supply	7.3.7.3	P
Addition of new solar array panels	7.3.7.4	P
Addition of new tape recorders	7.3.7.5	P
Maintenance of nutation damper locking system	7.3.7.6	P
Maintenance of arm locking system	7.3.7.7	P
Addition of stabilization magnets	7.3.7.8	S
Calibration of magnetometer	7.3.7.10	S
EVA documentation photography	6.3.6.9	P
Return OSO to automatic operation	7.3.7.11	P
Return to CM and stowage of materials	7.3.8	MSO
Release and capture mechanism jettison	7.3.9	MSO
Post-release inspection	7.3.10	
Determination of OSO dynamics	6.3.3.2	MSO
Documentation photography	6.3.3.3	MSO

As previsoulsy stated, each experiment task is described in further detail with respect to the following characteristics and requirements:

- Mission or missions effectivity
- Experiment priority

- Purpose and objective
- Objective description
- Constraints
- Procedure (A detail procedure is defined for each experiment task. Each detail procedure was used in estimating the EVA and IVA times for the experiment tasks. Refer to Section 5.)
- Hazard Conditions (defined as applicable)
- Accessibility
- Special tools and equipment
- Other support equipment
- Ground support equipment (defined as applicable)
- Astronaut training equipment
- Potential problem areas (defined as applicable)

A Mission 2 time line summary has been prepared and is included as Table 7-2.

Table 7-2
MISSION 2 TIME LINE SUMMARY

Operation/Event	Expr. Priority	EVA (Min)	IVA (Min)	Accured Mission Time (EVA + IVA) (Min)
I Rendezvous operations				
CSM/CWP docking	MSO		25	25
CSM orbit transfer	MSO		44	69
Close rendezvous maneuvers	MSO		9	78
Night time station keeping	MSO		31	109
Circumnavigation	MSO		6	115
Precapture inspection	MSO		60	175
Night time station keeping	MSO		31	206
OSO capture maneuvers	MSO		6	212
Sub Total			212	
II Work session No. 1				
Start EVA-egress forward hatch	MSO	5	5	222
Prepare equipment OSO Inspection	MSO	27	27	276
Astronaut rest period		5		281

Table 7-2 (Cont.)

	Operation/Event	Expr. Priority	EVA (Min)	IVA (Min)	Accured Mission Time (EVA + IVA) (Min)
	Mount EVA cameras	P	3	3	287
	Experiment preparation and radiation measures	MSO	36		323
	Astronaut rest period		6		329
	Satellite centering	MSO	21		350
	Power Bus removal and umbilical connect	MSO	12		362
	Astronaut rest period		6		368
	Mech. freedom and damage evaluation and photos	P	32		400
	Read magnetometer	S		32	432
	Add stabilization magnets	S	21		453
	Astronaut rest period		6		
	Stow equipment, return to CM	MSO	47	47	553
	Sub Total		227	114	
III	Astronaut 8 hr rest period				1033
IV	Work Session No. 2				
	Start EVA-egress forward hatch	MSO	5	5	1043
	Prepare equipment reposition platform	MSO	27	27	1097
	Astronaut rest period		5		1102
	Add tape recorders and photos[a]	P	80	15	1197
	Astronaut rest period		6		1203
	Correct nutation damper lock	P	25	15	1243
	Astronaut rest period		6		1249
	Add solar array panel and photos	P	39	15	1303
	Astronaut rest period		6		1309
	Stow equipment, return to CM	MSO	47	47	1403
	Sub Total		246	124	
V	Astronaut 8 hr rest period				1883
VI	Work session No. 3				
	Start EVA-egress forward hatch	MSO	5	5	1893
	Prepare equipment reposition platform	MSO	27	27	1947
	Correct arm locking system and photos[a]	P	105	15	2067
	Astronaut rest period		6		2073
	Add batteries and photos[a]	P	74	15	2162
	Astronaut rest period		6		2168
	Replenish pitch gas	P	25	8	2201

Table 7-2 (Cont.)

Operation/Event	Expr. Priority	EVA (Min)	IVA (Min)	Accrued Mission Time (EVA + IVA) (Min)
Replenish spin gas	P	16	8	2225
Astronaut rest period		6		2231
Stow equipment, return to CM	MSO	47	47	2325
Sub Total		317	125	
VII Release operations	MSO		36	2361
Mission 2 Totals		790	611	

[a]With astronaut rest periods as applicable

7.3.1 Capture Mechanism Docking

Refer to Section 6.3.1 for this mission operation which will be identical to that of Mission 1.

7.3.2 Rendezvous Maneuvers

Refere to Section 6.3.2 for this mission operation which will be identical to Mission 1.

7.3.3 Precapture inspection during Station Keeping

Refer to Sections 6.3.3.1, 6.3.3.2, and 6.3.3.3 for these mission operations which will be identical to Mission 1.

7.3.4 Capture Operations

Refer to Sections 6.3.4.1 and 6.3.3.3 for these mission operations which will be identical to Mission 1.

7.3.5 Post-Capture Inspection and Preparations

Refer to Sections 6.3.5.1, 6.3.5.2, and 6.3.5.4 for these mission operations which will be identical to mission 1. Additional post-capture inspection and preparation experiments will be accomplished on Mission 2 as defined in the paragraphs which follow for:

- OSO wheel power bus removal
- Documentation observations and photography

Presented below are the conditions and requirements which are in common with respect to conducting these experiment tasks.

CONSTRAINTS:

- Satellite commanded off
- Work platform adjusted to proper height
- Light source operating
- Astronaut initially in outboard position

HAZARD CONDITIONS:

- Normal edges and corners on sheet metal and machined surfaces
- Arms with high pressure gas spheres
- Close proximity of satellite wheel to astronaut helmet

ACCESSIBILITY:

- The overhead accessibility and the working position will be fair to poor
- Photographic tasks will have good accessibility

COMMON TOOLS AND EQUIPMENT:

- Adjustable work platform with astronaut fixity
- Artificial illumination with portable light
- Electrical umbilical
- Remote wheel positioner and lock
- Reel tether with clamp
- Tool box
- General purpose (GP) container

OTHER SUPPORT REQUIREMENTS:

- EVA astronaut
- EVA communications link with CM
- Procedural transmission from CSM to EVA astronaut
- Storage space in the CM for unexposed and exposed film containers

GROUND SUPPORT REQUIREMENTS: Photographic developing and printing facilities

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with OSO mockup, no suit
- Familiarization with OSO and work platform mockup, suit pressurized to 3.7 psi, 1 g
- Use of EVA tools
- Neutral buoyancy EVA simulation time line evaluation

7.3.5.3 OSO Wheel Power Bus Removal and Umbilical Attachment

MISSION(S) 2, 3
EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To remove the OSO external test console connector plug and to install the checkout umbilical

OBJECT DESCRIPTION: Power within the OSO satellite is interrupted unless a jumper circuit incorporated in the cover cap or the plug of one of the OSO power console test connectors is installed. This operation is completed on the launch stand after the ground umbilical connector is removed. In orbit, internal OSO power can be interrupted by removing this plug. Also, checkout of the OSO satellite in orbit can be accomplished by utilizing this connector. The connector and plug for OSO's F and G will be similar to the OSO II connector and plug which are Bendix part numbers PT02P-11S-005 and PT06P-18-11P-005 respectively. The plug and connector are located on the bottom side of compartment No. 8 adjacent to two other console test connectors which are covered with Bendix cap receptacles.

PROCEDURE:

(1) Orient and lock OSO wheel with connectors at work position.

(2) Astronaut moves inboard.

BBRC

(3) Remove connector removal tool with tether attached from tool box.

(4) Position removal tool on satellite internal power source connector.

(5) Remove connector.

(6) Place connector in general purpose container.

(7) Place removal tool in tool box.

(8) Remove CWP power umbilical line from stowed position.

(9) Position umbilical connector in satellite mating connector.

(10) Install connector.

(11) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT: Connector plug removal tool.

POTENTIAL PROBLEM AREAS: Connector may not be removable due to cold welding.

7.3.5.5 Documentation Observations and Photography

MISSION(S) 2, 3
EXPERIMENT PRIORITY Mission Support Operations

PURPOSE AND OBJECTIVE: To conduct visual and photographic documentation of the OSO satellite during the conduct of useful work tasks. By visual and photographic determination establish before and after historical records of the OSO appearance and configuration, before and after experiments can be conducted.

OBJECT DESCRIPTION: The OSO satellite is illustrated in Fig. 1-1. Before and after pictures and observations of particular interest will be taken for the following experiments and subjects:

- Addition of new battery power supply
- Addition of new solar array panels
- Addition of new tape recorders
- Addition of stabilization magnets

PROCEDURE: (For each picture sequence)

(1) Remove camera with tether from stowed position.

(2) Direct light on subject area.

(3) Focus and take picture of subject area.

(4) Return camera to stowed position.

SPECIAL TOOLS AND EQUIPMENT:

- General purpose 70 mm Maurer still picture camera with f/2.8 80 mm f. l. lens and colored film with tether.
- Storage containers for unexposed and exposed film.
- Artificial illumination.
- Place to store camera between picture taking operations.

POTENTIAL PROBLEMS:

- Adequate lighting of the areas to be photographed.

7.3.6 Material Retrieval

There have been no specific material retrieval experiments identified for Mission 2; however, material retrieval would be conducted as a secondary objective to any of the primary and mission support operations which yield material that can be retrieved.

7.3.7 Refurbishment

Refurbishment experiments for Mission 2 will consider the following tasks:

- Replenishment of pitch gas supply
- Replenishment of spin gas supply
- Addition of new power supply
- Addition of new solar array panels
- Addition of new tape recorders
- Maintenance of nutation damper locking system
- Maintenance of arm locking system
- Addition of stabilization magnets

- Calibration of magnetometer
- EVA documentation photography
- Return OSO to automatic operation

EVA documentation photography for Mission 2 will be accomplished as in Mission 1. (See Section 6.3.6.9.) The conditions and requirements required to accomplish the above experiment tasks are presented as follows:

CONSTRAINTS:

- Satellite commanded off
- Wheel umbilical power bus removed
- Sail section locked to the wheel
- Work platform adjusted to proper height
- Light sources operating
- Astronaut initially in outboard position
- Checkout by IVA astronaut initiated when EVA astronaut is in outboard position
- Stable dynamic balance of the OSO when experiment components are added

HAZARD CONDITIONS:

- Normal edges and corners on sheet metal and machined surfaces
- Arms with high pressure gas spheres
- Operating with high pressure gas system
- Close proximity of satellite wheel to astronaut helmet

ACCESSIBILITY: Accessibility for the experiments is rated as follows:

- Good for experiments adding equipment to wheel rim panel area
- Fair to poor for experiments requiring work on the bottom of the satellite, and in the back of the sail

COMMON TOOLS AND EQUIPMENT:

- Adjustable work platform with astronaut fixity
- Artificial illumination
- Portable light
- Remote wheel positioner and lock
- Device for locking sail
- Power tool for driving adaptive tools
- Reel tether with clamp
- Short tether
- Tool box
- General purpose (GP) storage container

OTHER SUPPORT REQUIREMENTS:

- EVA and IVA astronaut
- EVA communications link with CM
- Procedural transmission from CM to EVA astronaut
- CSM onboard checkout system (OCS)

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with OSO and gas supply mockup, no suit
- Familiarization with OSO, gas supply and work platform mockup; suit pressurized to 3.7 psig, environment 1 g
- Use of EVA tools
- Neutral buoyancy EVA simulation time line evaluation
- Familiarization with CSM onboard checkout system (OSC)

7.3.7.1 Replenishment of Pitch Gas Supply

MISSION(S) 2, 3
EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To replenish the depleted pitch gas system of the OSO while the satellite is in orbit, and restore the satellite pitch gas system into an extended operational condition.

OBJECT DESCRIPTION: The pitch gas control system is illustrated in Fig. 6-10. The check valve for replenishing the pitch gas supply system is located in the lower right hand corner of the sail structure. It is readily accessible from the side of the sail structure. (BBRC drawing E8011, Upper Section Assembly). The check valve has a threaded nipple to which the fill supply hose will be attached (BBRC drawing C8383, Check Valve). The check valve is covered with a cap (BBRC drawing B7774, Cap-Pressure Seal, Modified). The pitch gas system contains 4.4 pounds of nitrogen stored in a titanium bottle at 3000 ± 100 psig. At this pressure, the safety factor with respect to ultimate strength is 2.15. The pitch gas system operates at 30 psig nominal pressure.

CONSTRAINTS: Additional constraints affecting this experiment task are as follows:

For EVA astronaut

- Satellite commanded off
- Wheel umbilical power bus removed
- Light sources operating
- Sail section locked to wheel

For IVA astronaut

- Work platform stowed
- All EVA experiment tasks completed or abondoned.
- Satellite system checked out.
- Filling assemblies attached to satellite gas fill lines by EVA astronaut
- EVA astronaut in CM
- CM pressurized
- Satellite on internal power
- Boom umbilical lines stowed

PROCEDURE:

For EVA astronaut

(1) Orient and lock wheel with sail pitch gas filling line in position for work.

(2) Astronaut moves inboard.

(3) Attach reel tether to check valve fitting tool.

(4) Remove check valve fitting tool from tool box.

(5) Position fitting tool over check valve fitting.

(6) Attach fitting tool to sail structure.

(7) Remove reel tether.

(8) Remove power tool from tool box.

(9) Attach pitch gas cap removal tool to power tool.

(10) Position removal tool over pitch gas line cap.

(11) Remove pitch gas line cap.

(12) Place cap in general purpose container.

(13) Place cap removal tool in tool box.

(14) Place power tool in tool box.

(15) Attach reel tether to quick disconnect coupling.

(16) Position disconnect coupling on pitch gas line and hand thread.

(17) Remove reel tether.

(18) Attach reel tether to ratchet tool.

(19) Remove ratchet tool from tool box.

(20) Position ratchet tool over quick disconnect.

(21) Tighten quick disconnect to gas line.

(22) Place ratchet tool in tool box.

(23) Remove reel tether.

(24) Attach reel tether to check valve fitting tool.

(25) Remove check valve fitting tool.

(26) Place fitting tool in tool box.

(27) Remove reel tether.

(28) Remove gas supply line from stowed position.

(29) Using quick disconnect fitting, attach pitch gas supply line to sail quick disconnect fitting.

(30) Attach reel tether to sail lock.

(31) Remove sail lock short tether from sail structure.

(32) Remove sail lock from sail.

(33) Place sail lock in tool box.

(34) Remove reel tether.

(35) Astronaut moves outboard.

For IVA astronaut

(1) Unstow command controller.

(2) Attach controller umbilical power line to CM.

(3) Energize controller (stand by).

(4) Aim controller antenna thru window.

(5) Depress fill command button.

(6) Depress pressure read indicator.

(7) When pressure is at required value, depress pressure off button.

(8) Depress disconnect button.

(9) Inspect pressure lines and visually verify disconnect.

(10) Remove controller umbilical power line from CM.

(11) Stow controller.

SPECIAL TOOLS AND EQUIPMENT:

- Drive tool for removing and containing cap
- Remotely operated high pressure nitrogen gas supply
- Remotely operated attach fitting
- Power tool ratchet handle
- Check valve fitting tool
- Quick disconnect coupling
- Hand held command controller
- CM umbilical power connector

POTENTIAL PROBLEM AREAS:

- Operating with the high pressure gas system
- Gas line leakage

7.3.7.2 Replenishment of Spin Gas Supply

MISSION(S) 2, 3
EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To replenish the depleted spin gas system of the OSO while the satellite is in orbit in order to restore the satellite spin gas system into an extended operational condition.

OBJECT DESCRIPTION: The spin gas control system is illustrated in Fig. 6-10. The check valve for replenishing the spin gas supply system is located on the rim panel of wheel compartment No. 4 (BBRC drawing E8406). The check valve has a threaded nipple to which the fill supply hose will be attached (BBRC drawing C8383). Another cap is attached to the check valve (BBRC drawing B7774). The spin gas system contains 4.4 pounds of nitrogen stored in three titanium spheres at 3000 ± 100 psig. At this pressure, the safety factor with respect to ultimate strength is 2.15. The spin gas system operates at 30 psig nominal pressure.

OPERATION: The additional constraints, procedure, special tools and equipment, and potential problems areas which apply to the replenishment of the pitch gas system (Section 7.3.7.1) are also applicable for this experiment task.

7.3.7.3 Addition of New Battery Power Supply

MISSION(S) 2,3
EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To supplement the existing OSO battery power supply by adding battery packs. This operation is to be accomplished while the satellite is in orbit in order to enhance EVA technology and to restore the OSO power supply system into an extended operational condition.

OBJECT DESCRIPTION: Located around the OSO wheel section on compartments Nos. 3, 6, and 9 are three structural brackets which are used for ground handling (BBRC drawing 16410). Additional battery packs can be added to the OSO satellite by attaching them to these brackets, and connecting them to the power console test connectors located on the bottom of compartment No. 8. These connectors are described in Section 7.3.5.3.

PROCEDURE:

For EVA astronaut

(1) Orient and lock wheel with lifting bracket in position for battery pack attachment.

(2) Astronaut moves inboard.

(3) Attach reel tether to battery pack No. 1.

(4) Remove battery pack No. 1 from work platform.

(5) Position battery pack No. 1 on lifting bracket.

(6) Hold battery pack No. 1 with one hand.

(7) Start wing screws in lifting bracket tapped holes.

(8) Release battery pack No. 1.

(9) Remove reel tether.

(10) Remove power tool from tool box.

(11) Insert screw driving tool in power tool.

(12) Power drive screws into lifting bracket.

(13) Place screw driving tool in tool box.

(14) Place power tool in tool box.

(15) Astronaut moves outboard.

(16) Repeat Steps (1) through (15) two times for the other two brackets with battery pack Nos. 2 and 3.

(17) Translate work platform to wheel bottom position at battery back No. 1

(18) Astronaut moves inboard.

(19) Remove wire cable package from work platform.

(20) Attach reel tether to end of cable.

(21) Attach wire cable connector to battery pack No. 1.

(22) Remove reel tether.

(23) Astronaut moves outboard.

(24) Orient and lock wheel at next battery position.

(25) Astronaut moves inboard.

(26) Repeat Steps (19 through (25) two times for other two battery packs.

(27) Remove umbilical cable from battery pack No. 1.

(28) Attach added battery system umbilical cable to existing satellite umbilical line.

(29) Astronaut moves outboard.

IVA astronaut

(1) Energize CSM onboard checkout system (OCS)

(2) Monitor OSO power supply system.

(3) Ascertain that added battery packs are operating satisfactorily.

SPECIAL TOOLS AND EQUIPMENT:

- Three battery packs with cable harness and attachment screws
- Special storage container
- Screw driver adaptive tool

7.3.7.4 Addition of New Solar Array Panels

MISSION(S) 2

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To supplement the existing OSO solar array panel by adding additional solar arrays. This operation is to be accomplished while the satellite is in orbit in order to enhance EVA technology and to restore the OSO power supply system into an extended operational condition.

OBJECT DESCRIPTION: It is proposed to add new solar array panels to the sail section (BBRC drawing E8011). Located on the back of the sail structure are electrical connectors which can be used to feed the electrical power from the new solar array panels into the satellite.

CONSTRAINTS: Additional constraints affecting this experiment are as follows:

- Care must be taken not to contaminate solar cell surfaces or adjacent optic surfaces.
- Solar array surfaces must be protected from contamination during transportation and installation.

PROCEDURE:

EVA astronaut

(1) Orient and lock wheel in working position.

(2) Astronaut moves inboard (approximately mid-way).

(3) Attach reel tether to lens protectors.

(4) Install lens protectors on pointed experiments and solar sensors.

(5) Remove reel tether from lens protectors.

(6) Open solar array container.

(7) Move to inboard position.

(8) Attach reel tether to solar array.

(9) Remove solar array from container.

(10) Position solar array on sail.

(11) Lock accessible solar array clamps.

(12) Remove reel tether.

(13) Astronaut moves outboard.

(14) Rotate and lock wheel.

(15) Astronaut moves inboard.

(16) Lock balance of solar array clamps.

(17) Release sail clamp.

(18) Reposition sail and lock.

(19) Remove lens protective covers.

(20) Release sail clamp.

(21) Reposition sail and lock.

(22) Astronaut moves outboard.

(23) Orient and lock wheel.

(24) Astronaut moves inboard.

(25) Adjust portable lights.

(26) Remove connector removal tool with tether attached from tool box.

(27) Remove solar panel connector.

(28) Stow connector removal tool.

(29) Release new solar array connector from retaining clip.

BBRC

(30) Connect both solar array electric harness connectors together.

(31) Remove connector removal tool from tool box.

(32) Grip connector assembly with tool and connect into power source.

(33) Stow connector tool.

(34) Close solar array container.

(35) Stow portable light.

(36) Astronaut moves outboard.

IVA astronaut

(1) Energize CSM onboard checkout system (OCS).

(2) Monitor OSO power supply system.

(3) Ascertain that added solar array panels are operating satifactorily.

SPECIAL TOOLS AND EQUIPMENT:

(1) Solar array panels with electrical harness, connectors and attachment clamps.

(2) Solar array protective container.

(3) Electrical connector removal tool.

(4) Lens and solar cell protective covers.

7.3.7.5 Addition of New Tape Recorders

MISSION(S) 2, 3
EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To supplement the existing OSO tape recorder capability by adding additional tape recorders. This operation is to be accomplished while the satellite is in orbit in order to enhance EVA technology and to restore the OSO data storage capability into an extended operational condition.

OBJECTIVE DESCRIPTION: Located around the OSO wheel section on compartments Nos. 3, 6, and 9 are three structural brackets which are used for ground handling of the OSO (BBRC drawing D16410). Additional tape recorders can be added to the OSO satellite by attaching them to these brackets in conjunction with the added batteries and connecting them to the power console test connectors located on the bottom of compartment No. 8. These connectors are described in Section 7.3.5.3.

PROCEDURE:

EVA astronaut

(1) Orient and lock wheel with lifting bracket in position to attach tape recorder.

(2) Astronaut moves inboard.

(3) Attach reel tether to tape recorder No. 1.

(4) Remove recorder No. 1 from work platform.

(5) Position recorder No. 1 on satellite lifting bracket.

(6) Hold recorder No. 1 with one hand.

(7) Start wing screws into lifting bracket tapped holes.

(8) Release recorder No. 1.

(9) Remove reel tether.

(10) Remove power tool from tool box.

(11) Insert screw driving tool in power tool.

(12) Position screw driving tool in screw.

(13) Power drive screw.

(14) Repeat steps (12) and (13) as required.

(15) Place screw driving tool in tool box.

(16) Place power tool in tool box.

(17) Astronaut moves outboard.

BBRC

(18) Repeat Steps (1) thru (17) two times for recorder No. 2 and for ballast.

(19) Translate work platform to wheel bottom position.

(20) Astronaut moves inboard.

(21) Remove cable from recorder stowed position.

(22) Attach reel tether to cable connector.

(23) Astronaut moves outboard.

(24) Orient wheel and lock in position of second recorder.

(25) Astronaut moves inboard.

(26) Attach cable connector from previous recorder to recorder in position.

(27) Remove reel tether.

(28) Remove recorder cable from stowed position on recorder.

(29) Attach reel tether to connector.

(30) Astronaut moves outboard.

(31) Orient and lock wheel at wheel umbilical connectors.

(32) Astronaut moves inboard.

(33) Remove connector removal tool with tether attached from tool box.

(34) Remove satellite system umbilical connector.

(35) Place connector removal tool in tool box.

(36) Attach recorder connector to satellite system umbilical connector.

(37) Remove reel tether.

(38) Attach recorder and system combined connector into satellite wheel connector.

(39) Astronaut moves outboard.

IVA astronaut

(1) Energize CSM onboard checkout system (OCS)

(2) Operate the added tape recorders.

(3) Ascertain that added tape recorders are operating satisfactorily.

SPECIAL TOOL AND EQUIPMENT:

- Two tape recorders with cable harness and attachment screws
- Ballast with attachment screws
- Special storage container
- Screw driver adaptive tool

7.3.7.6 Maintenance of Nutation Damper Locking System (Typical)

MISSION(S) 2, 3
EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To release the nutation damper by energizing the retaining pin squib circuit in the case of a malfunction of the launch sequence timer. This experiment is presented as a typical maintenance experiment that could be accomplished if a malfunction to the OSO satellite occurred.

OBJECT DESCRIPTION: During the launch phase, the nutation damper is locked in position in order to better protect it from the launch and boost phase loads. After separation from the launch vehicle, the OSO launch sequence timer activates a squib circuit which extracts a retainer pin; thus frees the nutation damper. In the case of a failure such that the squib circuits did not fire, corrective action could be taken to fire the squib circuits from an auxiliary power supply. Electrical access to these squib circuits is available through an electrical connector located on the back side of the sail structure. The electrical connector for the nutation damper circuit is PT02P-10-005 (BBRC drawing E8011).

PROCEDURE:

(1) Orient and lock wheel.

(2) Astronaut moves inboard.

(3) Check elevation gimbal to ascertian that it is locked.

(4) Remove sail lock from tool box with short tether attached.

(5) Position sail to working position.

(6) Attach sail lock to sail.

(7) Remove connector removal tool with tether attached from tool box.

(8) Position tool and remove squib connector.

(9) Stow connector removal tool in tool box.

(10) Remove harness cutter with tether attached from tool box.

(11) While gripping connector with one hand, cut wire harness releasing connector.

(12) Stow connector in general purpose container.

(13) Stow harness cutter in tool box.

(14) Release auxiliary power supply harness from stowed position.

(15) Connect harness connector into squib circuit.

(16) Energize squib circuit with power.

(17) Check elevation gimbal to determine that it has been released.

(18) Disconnect auxiliary power supply connector.

(19) Stow harness.

(20) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

(1) Auxiliary power supply (CM electrical umbilical).

(2) Connector removal tool with tether attached.

(3) Wire cutter with tether.

POTENTIAL PROBLEM AREAS: Squib fire malfunction may not be a fault of the launch sequence timer; however, if sufficient current is applied for a maximum time, the probability is very high that the squib will fire.

7.3.7.7 Maintenance of Arm Locking System (Typical)

MISSION(S) 2, 3
EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To release the arm retention locks by energizing the retaining pin squib circuits in the case of a malfunction of the launch sequence timer. This experiment is presented as a typical maintenance experiment that could be accomplished if a malfunction to the OSO satellite occurred.

OBJECT DESCRIPTION: During the launch phase, the arms are locked in a down position to accommodate the launch vehicle space envelope requirements. After separation from the launch vehicle, the OSO launch sequence timer activates a series of squib circuits which extract three retaining pins, thus freeing the arms and allowing them to rotate out and up into their operational configuration. In the case of a failure such that the squib circuits do not fire, corrective action could be taken to fire the squib circuits from an auxiliary power supply. Electrical access to these squib circuits is through three electrical connectors located on the underside of the wheel section in compartments Nos. 1, 4, and 7 (BBRC drawing E8010).

PROCEDURE:

(1) Orient and lock wheel.

(2) Astronaut moves inboard.

(3) Adjust flood lights.

(4) Observe pin lock to determine that it has not released.

(5) Remove connector removal tool with tether attached from tool box.

(6) Remove connector from squib block.

(7) Place connector removal tool in tool box.

(8) Release power lead from auxiliary power supply and restow.

(9) Connect power lead to squib connector.

(10) Energize squib circuit with power.

(11) Remove power lead from squib block.

(12) Observe that pin has released. NOTE: If pin failed to release, repeat Steps (5) through (10) for second squib.

(13) Remove connector tool from tool box.

(14) Connect original connector into squib.

(15) Stow connector tool in tool box.

(16) Astronaut moves outboard.

(17) Orient and lock wheel at second arm.

(18) Repeat Steps (2) through (16) for second squib block.

(19) Orient and lock wheel at third arm.

(20) Repeat Steps (2) thru (16) for third squib block.

(21) Grip arm and raise arm into deployed position (all arms move together).

(22) Astronaut moves to outboard position.

SPECIAL TOOLS AND EQUIPMENT:

- Auxiliary power supply (CM electrical umbilical)
- Connector removal tool with tether attached

POTENTIAL PROBLEM AREAS: Similar to the potential problem cited in Section 7.3.7.6.

7.3.7.8 Addition of Stabilization Magnets

MISSION(S) 2, 3
EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To add permanent magnets to the OSO satellite in order to improve the OSO performance and thus add greatly to the scientific yield of the mission. This corrective measure will also aid in minimizing the expenditure of pitch and spin gas due to interaction of the OSO with the earth's magnetic field.

OBJECT DESCRIPTION: An electromagnetic coil is incorporated into the OSO control system which can be energized/de-energized by command from the ground to counteract the interaction between the OSO and the earth's magnetic field. Depending on the nature and magnitude of this interaction, it may be desirable to incorporate a permanent magnet, therby introducing a fixed bias to aid the function of the electromegnetic coil. If necessary, permanent magnets can be added to the back side of the side of the OSO sail structure (BBRC drawing E8011).

PROCEDURE:

(1) Orient and lock wheel in work position.

(2) Remove sail lock from tool box with tether attached.

(3) Position sail.

(4) Lock sail.

(5) Open storage container.

(6) Astronaut moves inboard.

(7) Attach reel tether to permanent magnet.

(8) Remove magnet from storage container.

(9) Position magnet on sail structure and lock clamp.

(10) Release reel tether.

(11) Release sail lock with tether attached.

(12) Rotate sail to new position.

(13) Lock sail.

(14) Attach reel tether to permanent magnet.

(15) Remove magnet from storage container.

(16) Position magnet on sail structure and lock clamps.

(17) Release reel tether.

(18) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Set of permanent magnets (two) with locking clamps.
- Storage container.

7.3.7.10 Calibration of Magnetometer

MISSION(S) 2, 3

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To calibrate the roll aspect magnetometer as a result of an induced error created by the addition of permanent magnets to the OSO sail structure. (See Section 7.3.7.8)

OBJECT DESCRIPTION: As a result of adding permanent magnets to the OSO sail structure, an error will be introduced into the measured data from the roll aspect magnetometer. One procedure for calibrating this error is to measure the roll angle before and after the installation of the magnetics with the CSM and OSO in the captured configuration. This would be accomplished by telemetrically measuring both the OSO data and the CSM inertial reference and then calculating the roll angle from both sets of data. The data obtained following the magnet installation should reveal any error in the magnetometer data.

PROCEDURES:

For EVA astronaut

(1) Orient and lock wheel with Astronaut positioned at center between two arms.

(2) Astronaut moves inboard.

(3) Release sail lock.

(4) Position sail with right side centered over satellite arm No. 1. (Orientation of the sail structure is relative to looking at the front side of the sail.)

(5) Lock sail.

(6) Astronaut moves outboard.

(7) IVA astronaut reads magnetometer data.

Repeat Steps (2) through (7) five times for the following sail positions:

a. Position sail with right side centered at wheel corner between satellite arms No. 1 and No. 2.

b. Position sail with right side centered over satellite arm No. 2.

c. Position sail with right side centered at wheel corner between satellite arms No. 2 and No. 3.

d. Position sail with right side centered over satellite arm No. 3.

e. Position sail with right side centered at wheel corner between satellite arms No. 3 and No. 1.

NOTE: Orientation of the sail structure is relative to looking at the front side of the sail.

For IVA astronaut

1. Energize Command Module inertial guidance system (IGS).

2. Record inertial reference in conjunction with recording magnetometer readings.

3. Telemeter data to ground stations for evaluation.

SPECIAL TOOLS AND EQUIPMENT: Data interface with CM telemetry subsystem

GROUND SUPPORT REQUIREMENTS:

- Interface with ground telemetry network.
- Digital computer facility for reducing magnetometer data.

7.3.7.11 Return OSO to Automatic Operation

MISSION(S) 2, 3
EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To put the satellite on internal power in preparation for returning the OSO to an operational configuration.

OBJECT DESCRIPTION: As discussed in Section 7.3.5.3, internal power to the OSO satellite is interrupted when the power console test connector is removed. In order to restore the OSO satellite to an operational configuration, this connector must be replaced. Replacing the connector will be a reverse operation to that of removing it.

PROCEDURE:

(1) Orient and lock wheel.

(2) Astronaut moves inboard.

(3) Remove connector removal tool with tether attached from tool box.

(4) Position tool on CWP power umbilical connector.

(5) Remove connector.

(6) Stow umbilical and connector on boom.

(7) Place connector removal tool in tool box.

(8) Attach reel tether to wheel umbilical power bus connector.

(9) Remove connector from stowed position (GP container).

(10) Position connector.

(11) Install connector.

(12) Remove reel tether.

(13) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT: Connector plug removal tool.

7.3.8 Return to CM and Stowage of Materials

Refer to Section 6.3.8 for this mission operation which is similar to Mission 1.

7.3.9 Release and Capture Work Platform Jettison

Refer to Section 6.3.9 for this mission operation which is identical to Mission 1.

7.4 EXPECTED SIGNIFICANT RESULTS

The major expected significant results for Mission 2 are:

- Evaluation of orbit transfer and techniques for rendezvous with a noncooperative satellite
- Extensive evaluation of capture and release techniques, and hardware
- Extensive evaluation of EVA technology
- Refurbishment of the target OSO in the following areas:

  a. Replenishment of the pitch and spin gas supplies

b. Addition of new batteries and solar array to correct for degraded power supply performance

c. Addition of new tape recorders to correct for degraded performance

d. Maintenance of possible malfunction of elevation and arm locking systems

e. Addition of magnets to improve stabilization characteristics

- Calibration of magnetometer
- Checkout of all refurbished functions
- Extensive EVA experience in performing useful work

7.5 INTEGRATED TIME LINE

The IVA and EVA time required to perfrom each task presented in Section 7.3 is summarized and integrated in a time line analysis for Mission 2 which is presented in Fig. 7-1.

7.6 TOOLS AND EQUIPMENT

The special tool and equipment requirements to conduct the experiments for ESMRO Mission 2 have been summarized in Table 7-3. A commonality usage of these tools is presented in the Tool Usage Chart, Table 7-4.

Table 7-3
SPECIAL TOOLS AND EQUIPMENT FOR MISSIONS 2 AND 3

Operation	Equipment
1. Post capture photography	1. Still camera
2. Pre-experiment preparation	1. Radiation monitor 2. Equipment transfer tether
3. Attachment head centering	1. Adhesive heating umbilical line
4. Wheel power bus and umbilical connection	1. Boom power umbilical line 2. Boom system umbilical line
5. Mechanical freedom and damage evaluation	
6. Emissivity measurement	1. Template 2. Spectroreflectometer 3. Template container
7. High resolution photography	1. High resolution lens 2. Camera mount and lighting source
8. Eye block replacement	1. Screw driving tool

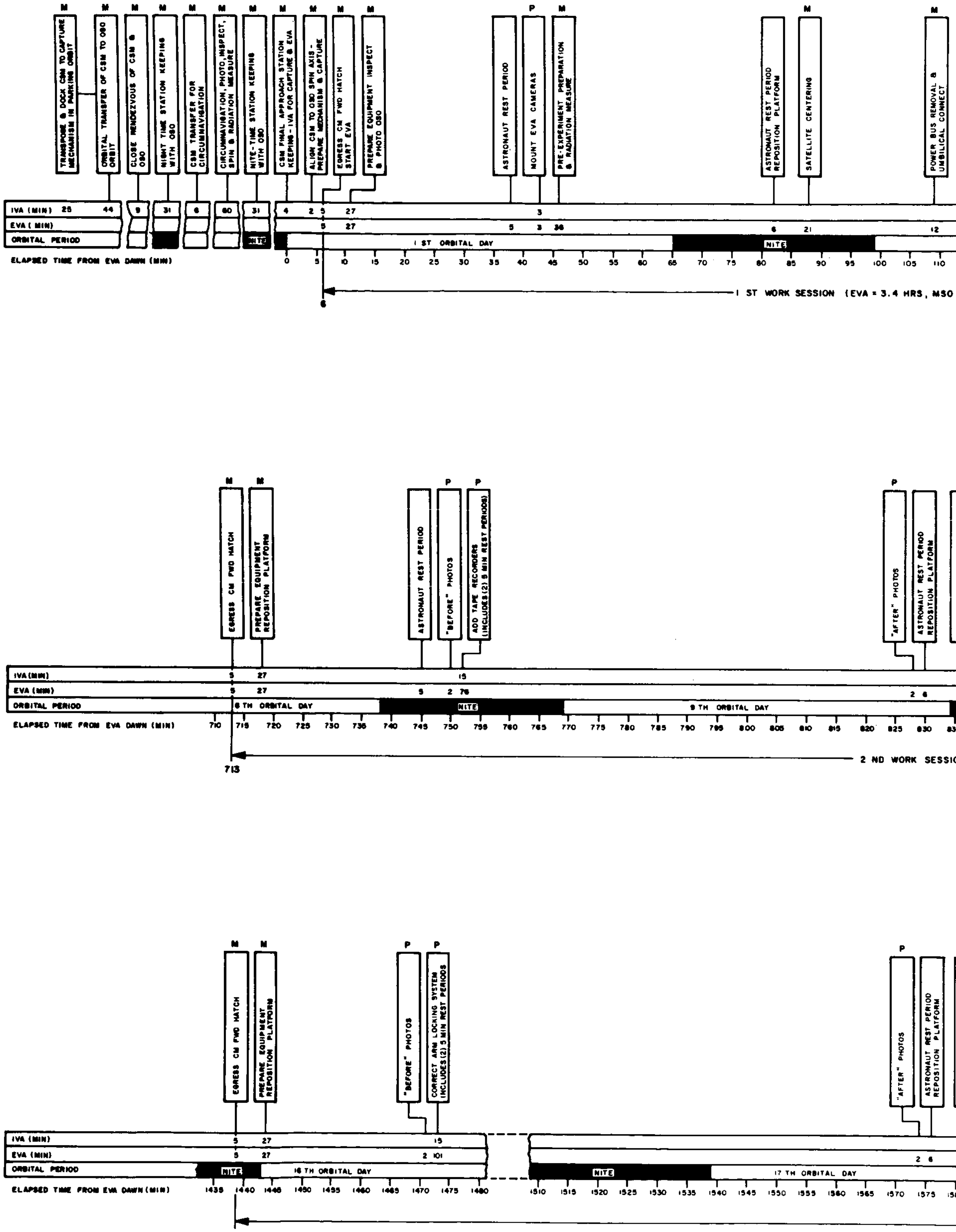
Table 7-3 (Cont.)

Operation	Equipment
	2. Pry bar with tether attached 3. Protective lens covers 4. Replacement eye block with container
9. Sail electronics component replacement	1. Latch release tool 2. Circuit board removal tool 3. Replacement board container 4. Replacement board
10. Correct elevation squibs	1. Auxiliary power supply 2. Wire harness cutter
11. Addition of solar array	1. Solar array 2. Solar array container
12. Addition of magnetic coil to sail	1. Magnetic coil 2. Container
13. Addition of permanent magnets to sail	1. Permanent magnets 2. Container
14. Magnetometer calibraiton	1. CSM checkout equipment
15. Correct arm retention locks	1. Auxiliary power supply
16. Battery addition	1. Screw driving tool 2. Batteries and cabling
17. Addition of tape recorders	1. Screw driving tool
18. Refurbish spin gas	1. Cap removal tool 2. Gas supply line 3. Remote filling and disconnect line

Table 7-4

TOOL USAGE CHART FOR MISSIONS 2 AND 3

Description	Post Capture Photography	Preexperiment Prep. & Radiation Monitoring	Attachment Head Centering	Wheel Power Bus Removal & Umbilical line Connection	Freedom & Damage Evaluation	Emmissivity Measurement	High Resolution Photography	Fine Eye Replacement	Sail Electronics Component Replacement	Correct Elevation Squibs	Addition of Solar Array Panels	Addition of Magnetic Coil to Sail	Addition of Permanent Magnets to Sail	Magnetometer Calibration	Correct Arm Retention Locks	Battery Addition	Tape Recorder Addition	Refurbish Spin Gas	Refurbish Pitch Gas	Satelite Internal Power Configuration	Return of Astronauts Experiments to CM
Remote wheel positioner and lock	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Work platform	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
EVA communications link	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Flood lights	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Portable lights							X				X										
Tool box			X	X				X	X	X	X				X	X	X	X	X	X	X
Astronaut tether	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Printed instruments elevation lock					X			X													
Sail lock					X	X		X	X	X	X	X	X	X		X	X				
Reel tether					X		X	X	X	X	X	X	X	X		X	X	X	X	X	
G. P. container								X	X	X								X	X		X
Pressurized or vacuum container								X			X										X
Vented container																					
Still camera	X				X		X														
Time sequence camera	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Power tool			X					X								X	X	X			
Connector removal tool with tether				X						X	X				X		X			X	



NOTES: SCALE - .10 = 1 MINUTE ORBITAL DAY = 65.2 MINUTES ORBITAL NITE = 31.0 MINUTES M = MISSION SUPPORT OPERATION P = PRIMARY S = SECOND[A]

IVA TIME REPRESENTS DIRECT SUPPORT IN PERFORMANCE OF ESMRO MISSION TASKS

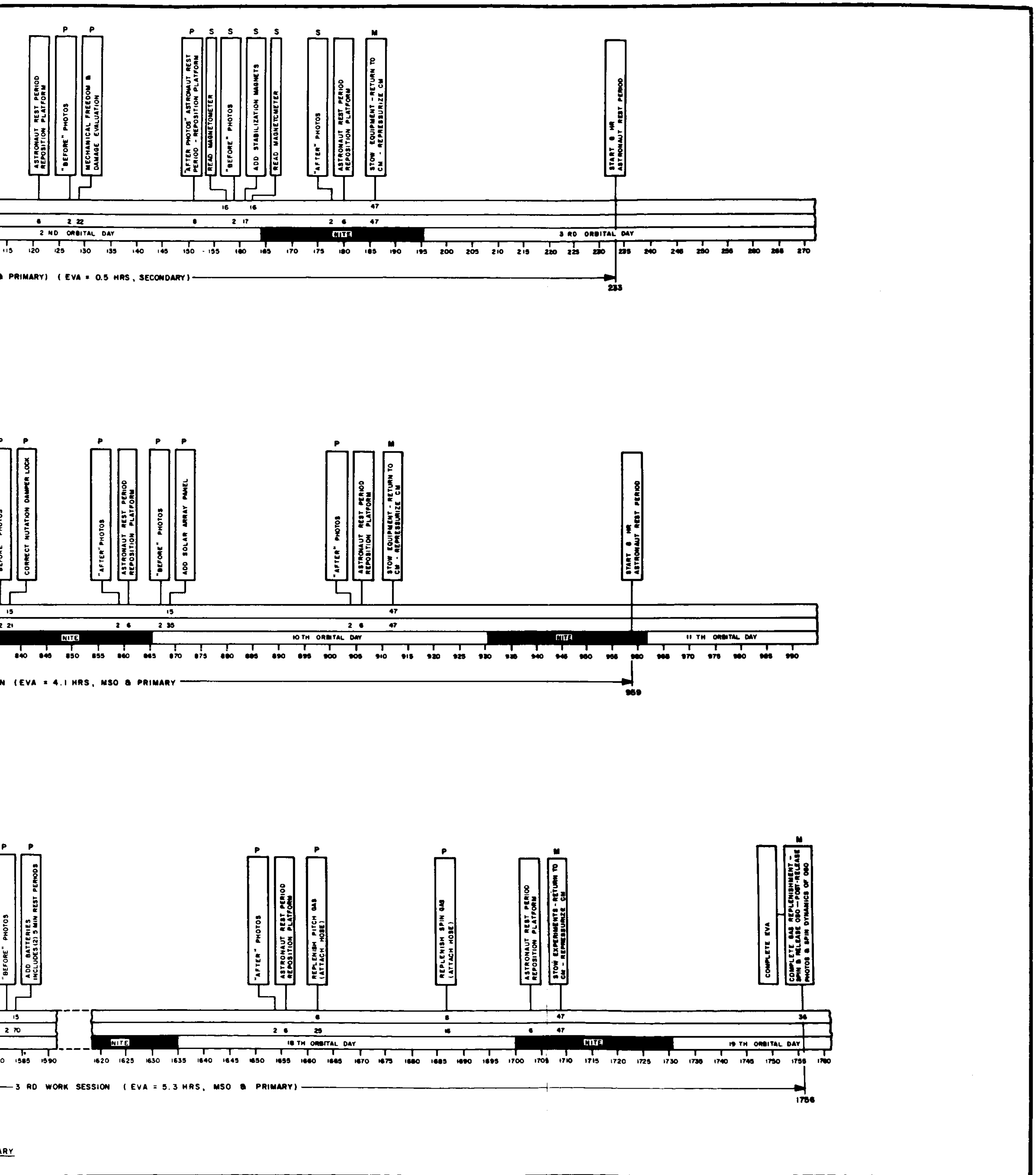


Fig. 7-1 Mission 2 Time Line Analysis

SECTION 8

MISSION 3 PROGRAM PLAN

Section 8
MISSION 3 PROGRAM PLAN

This section includes the details for the ESMRO Mission 3 program plan. This is the second refurbishment mission and is to be performed following Mission 2. The major advances made in this Mission 3 program plan are: (1) advanced refurbishment operations; and (2) improved refurbishment techniques accommodated by modifications to the target OSO.

8.1 MISSION OBJECTIVE

The primary objective of Mission 3 is to rendezvous with, capture, perform useful work, and release the OSO into an operational orbit. The useful work is to consist primarily of advanced refurbishment and checkout of the OSO satellite, in order to improve or extend its operation in orbit. Secondary objectives include evaluation of capture techniques and EVA technology.

8.2 MISSION CHARACTERISTICS

8.2.1 Time Frame

Mission 3 can be performed in the 1970 to 1971 time frame.

8.2.2 Target OSO

The target OSO for Mission 3 should be one that is partially or fully operational and/or has a high probability of being reactivated; extended operation should yield significant new scientific or technological data. The target OSO is specially modified to permit and facilitate the advanced refurbishment activites. The candidate OSO's that could be modified for this mission are OSO H, OSO I or OSO J.

8.2.3 Orbital Conditions

8.2.3.1 CSM

The mission will be initiated with the CSM in a 370 km (200 nautical mile) altitude parking orbit, at an inclination compatible with the OSO orbit. The CSM is to be launched so that the longitude of its ascending node is within ±2 degrees of the target OSO, and approaching from the east.

8.2.3.2 OSO

The target OSO will be in an orbit that has the following nominal parameters:

- Circular Orbit: 555 ± 92 km (300 ± 50 nautical miles)

- Inclination: 33 ± 3 deg
- Period: 96 min

8.3 MISSION OPERATIONS

The mission operations consist of the following functional steps:

- Capture mechanism docking
- Rendezvous maneuvers
- Precapture inspection during station keeping
- Capture
- Post-capture inspection and preparation
- Material retrieval
- Refurbishment and checkout
- Stowage of materials
- Release and capture mechanism jettison
- Post-release inspection

Each of these functional steps include tasks that are unique in the accomplishment of the mission. These tasks are discussed in detail in this section and are itemized in Table 8-1. The level of detail description is intended to define the scope of the major tasks; it does not include details on general mission support operations. Also indicated in this table are the reference section numbers and designations of the task priority (MOS, S, and P)

Many of the mission support operation and primary and secondary experiment tasks are the same for Missions 1, 2, and 3; therefore, the reference Section number is explained in either Section 6.3 or 7.3. Descriptions for these tasks are not repeated in this mission plan, since they are available in the reference sections.

Table 8-1
SUMMARY OF MISSION 3 OPERATION TASKS

Experiment	Reference Section No.	Priority
Capture mechanism docking	8.3.1	MSO
Rendezvous maneuvers	8.3.2	MSO
Precapture inspection during station keeping	8.3.3	
Determination of OSO radioactive levels	6.3.3.1	MSO
Determination of OSO dynamics	6.3.3.2	MSO
Documentation photography	6.3.3.3	MSO
Capture operations	8.3.4	N.A.
CSM maneuvers and OSO capture	6.3.4.1	MSO
Documentation photography	6.3.3.3	MSO
Post-capture inspection and preparation	8.3.5	
Experiment preparation and radiation monitoring	6.3.5.1	MSO
OSO centering	6.3.5.2	MSO
OSO wheel power bus removal and umbilical attachment	7.3.5.3	MSO
Mechanical freedom and damage evaluation	6.3.5.4	P
Documentation observations and photography	7.3.5.5	MSO
High resolution photography	8.3.5.6	S
Satellite emissivity measurements	8.3.5.7	S
Material retrieval	8.3.6	S
Replaced control sensor assembly	8.3.7.2	S
Retrieval of experiment optics or sensors	8.3.7.3	S
Refurbishment and checkout	8.3.7	
Replenishment of pitch gas supply	7.3.7.1	P
Replenishment of spin gas supply	7.3.7.2	P
Addition of new battery power supply	7.3.7.3	P
Addition of new solar array panels	7.3.7.4	P
Addition of new tape recorders	7.3.7.5	P
Replacement of pointing control electronics	8.3.7.1	P
Replacement of control sensor assembly	8.3.7.2	P
Replacement of experiment optics or sensors	8.3.7.3	P
Maintenance of nutation damper locking system	7.3.7.6	P
Maintenance of arm locking system	7.3.7.7	P
Addition of stabilization magnets	7.3.7.8	S
Addition of stabilization torquing coils	8.3.7.9	S
Calibration of magnetometer	7.3.7.10	S
EVA documentation photography	6.3.6.9	P
Return OSO to automatic operation	7.3.7.11	P
Return to CM and stowage of materials	8.3.8	MSO
Release and capture mechanism jettison	8.3.9	MSO
Post-release inspection	8.3.10	
Determination of OSO dynamics	6.3.3.2	MSO
Documentation photography	6.3.3.3	MSO

As previously stated, each experiment task is described in further detail with respect to the following characteristics and requirements:

- Mission, or missions effectivity
- Experiment priority
- Purpose and objective
- Objective description
- Constraints
- Procedure (A detail procedure is defined for each experiment task. Each detail procedure was used in estimating the EVA and IVA times for the experiment task. Refer to Section 5.)
- Hazard Conditions (defined as applicable)
- Accessibility
- Special tools and equipment
- Other support equipment
- Ground support equipment (defined as applicable)
- Astronaut training equipment
- Potential problem areas (defined as applicable)

A Mission 3 time line summary has been prepared and is included as Table 8-2.

8.3.1 Capture Mechanism Docking

Refer to Section 6.3.1 for this mission operation (which will be identical to Mission 1).

8.3.2 Rendezvous Maneuvers

Refer to Section 6.3.2 for this mission operation (which will be identical to Mission 1).

Table 8-2
MISSION 3 TIME LINE SUMMARY

Operation/Event	Experiment Priority	EVA (Min)	IVA (Min)	Accrued Mission Time (EVA + IVA) (Min)
I Rendezvous operations				
CSM/CWP docking	MSO		25	25
CSM orbit transfer	MSO		44	69
Close rendezvous maneuvers	MSO		9	78
Night time station keeping	MSO		31	109
Circumnavigation	MSO		6	115
Precapture inspection	MSO		60	175
Night time station keeping	MSO		31	206
OSO capture maneuvers	MSO		6	212
Sub Total			212	
II Work session No. 1				
Start EVA-egress forward hatch	MSO	5	5	222
Prepare equipment and OSO inspection	MSO	27	27	276
Astronaut rest period		5		281
Mount EVA cameras	P	3	3	287
Experiment preparation and radiation measurement	MSO	36		323
Astronaut rest period		6		329
Satellite centering	MSO	21		350
Power bus removal and umbilical connect	MSO	12		362
Astronaut rest period		6		368
Mechanical freedom and damage evaluation and photos	P	32		400
Replace experiment optics/sensors and photos	S	24	15	739
Astronaut rest period		6		445
Replace control sensor assembly and photos	S	32	15	492
Astronaut rest period		6		498
Stow equipment, return to CM	MSO	47	47	592
Sub Total		268	112	
III Astronaut 8 hr rest period				1072
IV Work session No. 2				
Start EVA-egress forward hatch	MSO	5	5	1082
Prepare equipment reposition platform	MSO	27	27	1136
Astronaut rest period		5		1141
High resolution photography[a]	S	76		1217
Astronaut rest period		5		1222

Table 8-2 (Cont.)

Operation/Event	Experiment Priority	EVA (Min)	IVA (Min)	Accrued Mission Time (EVA + IVA) (Min)
Satellite emissivity measurements[(a)]	S	50		1272
Astronaut rest period	S	5		1277
Correct nutation damper lock and photos	P	25		1302
Astronaut rest period		6		1308
Add solar panel and photos	P	39	15	1362
Astronaut rest period		6		1368
Stow equipment, return to CM	MSO	47	47	1462
Sub Total		296	94	
V Astronaut 8 hr rest period				1942
VI Work session No. 3				
Start EVA-egress forward hatch	MSO	5	5	1952
Prepare equipment reposition platform	MSO	27	27	2006
Read magnetometer	S		16	2022
Add stabilization Elec./Mag. coils and photos	S	22		2044
Astronaut rest period		6		2050
Correct arm locking system and photos(a)	P	105		2155
Astronaut rest period		6		2161
Add batteries and photos[(a)]	P	74	15	2250
Stow Equipment, return to CM	MSO	47	47	2344
Sub Total		292	110	
VII Astronaut 8 hr rest period				2824
VIII Work session No. 4				
Start EVA-egress forward hatch	MSO	5	5	2834
Prepare equipment reposition platform	MSO	27	27	2888
Add tape recorders and photos[(a)]	P	80	15	2983
Astronaut rest period		6		2989
Replace pointing control electronics and photos	P	24	15	3028
Astronaut rest period		6		3034
Replenish pitch gas supply	P	25	8	3067
Replenish spin gas supply	P	15	8	3090
Astronaut rest period		5		3095
Stow equipment, return to CM	MSO	47	47	3189
Sub Total		240	125	
IX Release operations	MSO		36	3225
Mission III Totals		1096	689	

(a) With astronaut rest periods as applicable

8.3.3 Precapture Inspection During Station Keeping

Refer to Sections 6.3.3.1, 6.3.3.2, and 6.3.3.3. for these mission operations (which will be identical to Mission 1).

8.3.4 Capture Operations

Refer to Sections 6.3.4.1 and 6.3.3.3 for these mission operations (which will be identical to Mission 1).

8.3.5 Post-Capture Inspection and Preparation

Refer to paragraphs 6.3.5.1, 6.3.5.2, 6.3.5.4, 7.3.5.3 and 7.3.5.5 for these mission support operations which will be identical to Missions 1 and 2, as applicable. Additional inspection tasks to be accomplished on Mission 3 are as follows:

- High resolution photography
- Satellite emissivity measurements

Presented below are the conditions and requirements which are in common with respect to conducting these experiment tasks.

CONSTRAINTS:

- Satellite commanded off
- Wheel umbilical power bus removed
- Sail locked to wheel
- Elevation gimbal locked
- Light source operating
- Work platform adjusted to proper height
- Astronaut initially in outboard position
- Care exercised to minimize contamination to areas on which photographs are take (Experiment areas selected will determine exact procedures.)

HAZARD CONDITIONS:

- Normal edges and corners on sheet metal and machined surfaces
- Arms with high pressure gas spheres

ACCESSIBILITY: Good to fair, depending on the subject area to be photographed, and emissivity measurements to be taken.

COMMON TOOLS AND EQUIPMENT:

- Adjustable work platform with astronaut fixity
- Artificial illumination with portable light
- Remote wheel positioner and lock
- Sail lock
- Reel tether with clamp

OTHER SUPPORT REQUIREMENTS:

- EVA astronaut
- EVA communications link with CM
- Procedural transmission from CM to EVA astronaut
- Storage space in CM for returning exposed film to earth

GROUND SUPPORT REQUIREMENTS: Photographic developing and printing facilities

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with OSO, no suit
- Familiarization with camera operation
- Familiarization with spectroreflectometer
- Familiarization with OSO and work platform mockup, wearing suit pressurized to 3.7 psig in a 1 g environment
- Neutral buoyancy EVA simulation for time line evaluation

8.3.5.6 High Resolution Photography

MISSION(S) 3

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To obtain high resolution photography of specific items and surfaces of the OSO satellite to determine erosion, contamination, and micrometeorite penetration effects due to long term exposure to space environment.

OBJECT DESCRIPTION: Photographic procedures must be carefully planned and controlled if they are to result in meaningful information with regard to erosion, contamination, and micrometeorite effects. In order to be useful, prelaunch pictures taken under identical conditions must be compared with the pictures taken of the satellite in orbit.

Specific items to be observed include the various exterior panels, thermal control surfaces, all optical surfaces, experiment doors and particular parts of experiments such as foil covers, optical surfaces of lenses and mirrors, etc. Signs of contamination should be looked for at critical places such as the silastic rubber bumper for the frame containing the pointed experiments. Anything of interest observed here should be included photographically if at all possible.

Lighting conditions, exposure time and lens-to-object distance setting must be precise. Color film will be of greatest value, and the artificial illumination must have a spectral characteristic which makes optimum use of the emulsion capability. A standard color disc will be included to appear at the edge of each frame. Protection of the film from all possible affects of space radiation is imperative.

CONSTRAINTS: (OSO Modifications) Pre-launch pictures taken under identical conditions must be taken of each selected area for photographing.

The exposed film packs must be protected against radiation.

PROCEDURE:

(1) Orient wheel and lock.

(2) Astronaut moves inboard.

(3) Attach reel tether to satellite camera mount.

(4) Remove camera mount from work platform.

(5) Attach camera mount to satellite.

(6) Remove reel tether.

(7) Attach reel tether to camera.

(8) Remove camera lens (lens stays in hold down).

(9) Position camera over high resolution lens.

(10) Attach high resolution lens.

(11) Remove camera and lens from hold down.

(12) Attach camera to mount.

(13) Position camera and mount for photograph.

(14) Set camera timer.

(15) Release camera shutter.

(16) Index film.

(17) Repeat steps (13) through (16) as required for each area to be photographed.

(18) Remove camera from mount.

(19) Place camera in platform hold down.

(20) Remove high resolution lens (lens stays in hold down).

(21) Position camera over regular lens.

(22) Attach regular lens.

(23) Return camera to stowed position.

(24) Remove reel tether.

(25) Attach reel tether to camera mount.

(26) Remove mount from satellite.

(27) Attach camera mount to work platform.

(28) Remove reel tether.

(29) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Camera with high resolution lens
- Adjustable camera mount (includes special artificial illumination)

- Colored film
- Protective container for film packs

POTENTIAL PROBLEM AREAS: Obtaining high quality scientific photographs in other than a laboratory environment

8.3.5.7 Satellite Emissivity Measurements

MISSION(S) 3

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To take emissivity measurements at selected areas on the OSO satellite to determine emissivity changes of material surfaces resulting from long term exposure to a space environment.

OBJECT DESCRIPTION: The OSO satellite is composed of a variety of material surfaces and materials, several of which would present excellent test surfaces for emissivity measurements to obtain additional data points for long term space exposure. Further, an experiment of this type on Mission 3 could be prearranged to provide for measurement of specific satellite surface characteristics prior to launch so that calibration and reference points could be obtained to compare with the measurements taken in orbit. This experiment is presented as a typical operation.

CONSTRAINTS: (OSO Modifications) Selected surfaces for prelaunch calibration and in-orbit emissivity measurements must be provided.

PROCEDURE:

(1) Orient and lock wheel in position.

(2) Open template container.

(3) Make ready emissivity sensor and recorder.

(4) Astronaut moves inboard.

(5) Remove template with tether attached from container.

(6) Position template on surface to be measured.

(7) Clamp template in place.

(8) Remove sensor head from container.

(9) Engage sensor head in template guides.

(10) Make emissivity measurement.

(11) Remove sensor head from template.

(12) Stow sensor head.

(13) Release template clamps and remove template.

(14) Stow template in container.

(15) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Spectroreflectometer
- Template with holding fixture
- Template container

8.3.6 Material Retrieval

Material retrieval for Mission 3 will be accomplished as a secondary objective, and as defined in paragraphs 8.3.7.1, 8.3.7.2, and 8.3.7.3. Special sensors can be added to the OSO satellite for the purpose of retrieval as a part of the Mission 3 experiment tasks.

8.3.7 Refurbishment and Checkout

Refer to Sections 7.3.7.1, 2, 3, 4, 5, 6, 8, 10, and 11, and 6.3.6.9 for these mission operations which will be identical to Missions 2 and 1, as applicable. Additional refurbishment experiments to be accomplished on Mission 3 are as follows:

- Replacement of pointing control electronics
- Replacement of control sensor assembly
- Replacement of experiment optics or sensors
- Addition of stabilization torquing coils

Presented below are the conditions and requirements which are in common with respect to conducting these experiment tasks.

CONSTRAINTS: The constraints are as follows:

- Satellite commanded off
- Wheel umbilical power bus removed
- Sail locked to wheel
- Pointed experiment frame in fixed position
- Light sources operating
- Work platform adjusted to proper height
- Astronaut in outboard position

Furthermore: (1) The IVA astronaut must not initiate checkout until EVA astronaut is in outboard position; (2) care must be taken not to contaminate adjacent instrument and satellite optics and sensors; and (3) inert gas storage containers for replaced parts and equipment must be provided.

HAZARD CONDITIONS:

- Normal edges and corners on sheet metal and machined surfaces.
- Arms with high pressure gas spheres

ACCESSIBILITY: Good

COMMON TOOLS AND EQUIPMENT:

- Adjustable work platform with astronaut fixity
- Artificial illumination with portable light
- Remote wheel positioner and lock
- Device for sail lock
- Device for locking pointed instruments elevation frame
- Reel tether with clamp
- Pry bar with tether
- Tool box

- Power tool for driving adaptive tools
- Short tether
- General purpose container

OTHER SUPPORT REQUIREMENTS:

- EVA and IVA astronaut
- EVA communications link with CM
- Procedural transmission from CM to EVA astronaut
- CSM onboard checkout system (OCS)
- Storage space in the CM for returning containers to earth

GROUND SUPPORT REQUIREMENTS:

- Clean room laboratory for post-flight analysis

ASTRONAUT TRAINING REQUIREMENTS:

- Familiarization with CSM onboard checkout system
- Familiarization with OSO and scientific instrumentation (no suit)
- Familiarization with OSO and work platform mockups (in suit pressurized to 3.7 psig in a 1 g environment)
- Use of EVA tools
- Neutral buoyancy, EVA simulation for time line evaluation

8.3.7.1 Replacement of New Pointing Control Electronics (Typical)

MISSION(S) 3

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To replace pointing control electronics to improve the pointing capability of the OSO satellite or to correct a malfunction that may have occurred after the satellite has been injected into orbit. This experiment is presented as a typical task that could be accomplished if such a malfunction to the OSO satellite occurred.

OBJECT DESCRIPTION: There are two electronic assembly packages located on the back side of the sail structure. The pointing control electronics assembly is located to the left side of the pointed experiments, and is shown in Fig. 8-1 for OSO II with the cover door removed. The pointing control electronics assembly is comprised of a series of printed circuit boards which slide into the assembly container. Access to the boards is to be obtained by removing the container cover (BBRC drawings E8011 and E7753).

The object of this experiment is to replace one of the printed circuit boards. This task can be simplified considerably by a modification to the assembly container design with the incorporation of a hinged door with wing nut latches.

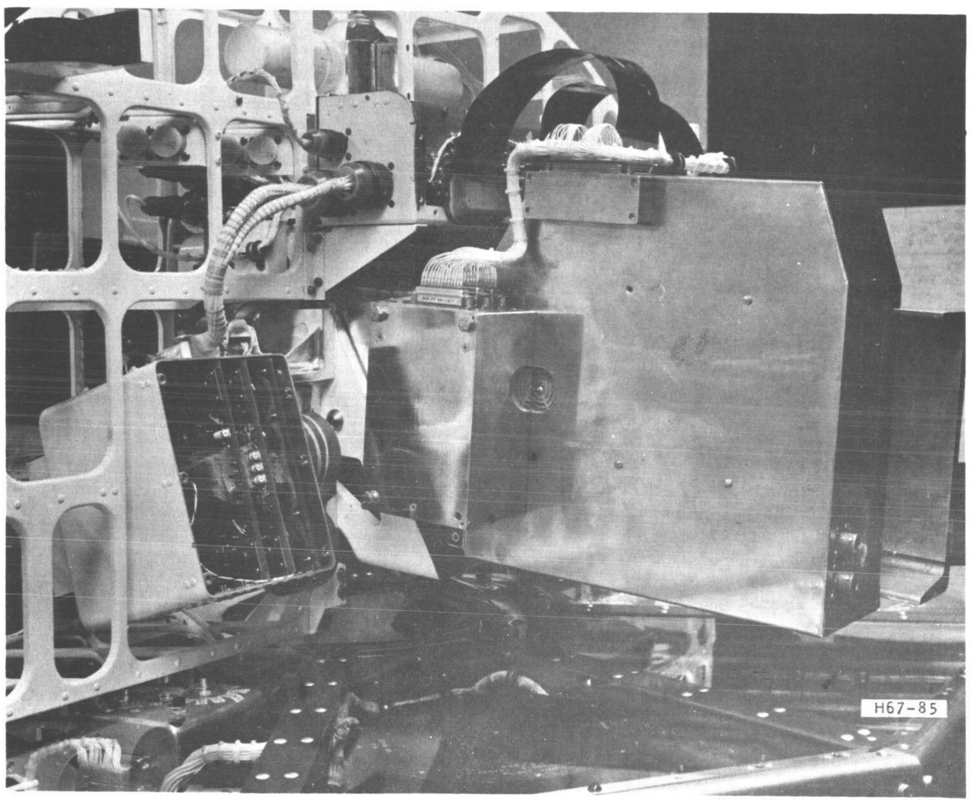


Fig. 8-1 ARCRL Experiment - Rear View

CONSTRAINTS: An additional constraint affecting this experiment is the provision of a hinge door with wing nut latches on the pointing control electronics assembly.

PROCEDURE:

For EVA astronaut

(1) Orient and lock wheel in position.

(2) Astronaut moves inboard.

(3) Remove sail lock with short tether attached to sail structure.

(4) Position sail to work position.

(5) Install sail lock.

(6) Attach reel tether to latch release tool.

(7) Remove tool from tool box.

(8) Open electronic assembly access door latches.

(9) Place tool in tool box.

(10) Attach reel tether to circuit board removal tool.

(11) Remove tool from tool box.

(12) Release circuit board.

(13) Place tool in tool box.

(14) Remove reel tether from tool.

(15) Attach reel tether to circuit board.

(16) Remove circuit board from electronic assembly.

(17) Place circuit board in special container.

(18) Remove reel tether.

(19) Open replacement circuit board container.

(20) Attach reel tether to circuit board.

(21) Remove circuit board from container.

(22) Place circuit board in electronic assembly.

(23) Lock circuit board in place.

(24) Remove reel tether.

(25) Attach reel tether to latch release tool.

(26) Remove tool from tool box.

(27) Close access door.

(28) Lock access door latches.

(29) Place latch release tool in tool box.

(30) Remove reel tether.

(31) Close replacement board container.

(32) Astronaut moves outboard.

For IVA astronaut

(1) Energize CSM onboard checkout system (OCS)

(2) Monitor pointing control electronics subsystem

(3) Ascertain that electronics are operating satisfactorily in accordance with special checkout procedures provided

SPECIAL TOOLS AND EQUIPMENT:

- Replacement printed circuit board
- Latch release tool
- Printed circuit board removal tool
- Special storage container

POTENTIAL PROBLEM AREAS: The printed circuit board may be difficult to remove.

8.3.7.2 Replacement of Experiments Optics or Sensors (Typical)

MISSION(S) 3

EXPERIMENT PRIORITY Primary

PURPOSE AND OBJECTIVE: To replace the optics or sensors of one of the pointed experiments in order to improve the data measurement capability, or to correct a malfunction that may have occurred after the satellite has been injected into orbit. This experiment is presented as a typical task that could be accommplished if such a malfunction to the OSO satellite occurred.

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OBJECT DESCRIPTION: Many of the OSO scientific experiments utilize optics or detectors which degrade with continued exposure to the sun's radiation for a long period of time. Changes in the transmission characteristics of optical elements or in the cathode efficiency of detectors are known to occur alter long term operation. Refurbishment of such elements would enhance the extended operation of the affected experiment and improve the scientific yield of the mission. The primary experiments that may experience such degradation are the pointed experiments located in the sail structure. Refurbishment of the optics or detectors could be accomplished by replacement of the old elements with new ones. Access to these elements, near the front or rear of the instrument, could be made through access ports in the side or top of the instrument case. This type of replacement experiment can only be performed on scientific instruments that can have access capability and proper alignment registration designed in before launch.

CONSTRAINTS: Additional constraints affecting this experiment are:

- To provide access into the scientific instrument optics or sensors with removable fasteners
- To provide automatic registration within the scientific instrument for the astronaut to check and adjust alignment

PROCEDURE:

For EVA astronaut

(1) Orient and lock wheel in position.

(2) Astronaut moves inboard.

(3) Remove sail lock with short tether attached to sail structure.

(4) Position sail to work position.

(5) Install sail lock.

(6) Install pointed experiment elevation frame lock.

(7) Attach reel tether to latch release tool.

(8) Remove tool from tool box.

(9) Open instrument access door latches.

(10) Place tool in tool box.

(11) Attach reel tether to optic/sensor removal tool.

(12) Remove tool from tool box.

(13) Release optic/sensor.

(14) Place tool in tool box.

(15) Attach reel tether to optic/sensor.

(16) Remove optic/sensor from instrument.

(17) Place optic/sensor in special container.

(18) Remove reel tether.

(19) Open replacement optic/sensor container.

(20) Attach reel tether to optic/sensor from container.

(21) Remove optic/sensor from container.

(22) Place optic/sensor in instrument.

(23) Lock optic/sensor in place.

(24) Remove reel tether.

(25) Attach reel tether to latch release tool.

(26) Remove tool from tool box.

(27) Close access door.

(28) Lock access door latches.

(29) Place latch release tool in tool box.

(30) Remove reel tether.

(31) Close replacement board container.

(32) Astronaut moves outboard.

For IVA astronaut

(1) Energize CSM onboard checkout system (OCS)

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(2) Monitor scientific instrument.

(3) Ascertain in accordance with prescribed procedures that scientific instrument is operating satisfactorily.

SPECIAL TOOLS AND EQUIPMENT:

- Replacement optics or sensor
- Latch release tool
- Optic/sensor removal tool
- Special stowage container

POTENTIAL PROBLEM AREAS:

- Possible difficulty in removing the instrument optics or sensors
- Obtaining alignment and calibration of newly installed optic or sensor

8.3.7.3 Replacement of Control Sensor Assembly

MISSION(S) 3

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To remove the control sensor assembly mounted on the pointed experiments, and replace with a new assembly. This experiment would be conducted if ground evaluation of telemetry measurement data indicated that degradation had taken place in the control sensor assembly, or if more precise pointing could be obtained with a recalibrated fine eye assembly.

OBJECT DESCRIPTION: The removal of the OSO II fine eye assembly which is typical of this operation is defined in detail in paragraph 6.3.6.2. The replacement of the control sensor assembly would entail removing the existing assembly and replacing with a new assembly.

PROCEDURE:

(1) Orient and lock wheel with eye block in work position.

(2) Astronaut moves inboard.

(3) Attach reel tether to lens cover.

(4) Remove lens cover from container.

(5) Attach lens cover to eye block.

(6) Remove power tool from tool box.

(7) Install screw driving tool in power tool.

(8) Position driving tool on screw.

(9) Remove screw.

(10) Place screw and washer if attached in tool box.

(11) Repeat steps (8) through (10) two times for remaining two screws.

(12) Place screw driving tool in tool box.

(13) Place power tool in tool box.

(14) Open eye block container.

(15) Remove pry bar with tether attached from tool box.

(16) Pry eye block loose from electrical connector.

(17) Place pry bar in tool box.

(18) Remove eye block.

(19) Place eye block in container.

(20) Remove reel tether.

(21) Close eye block container.

(22) Open new eye block container.

(23) Attach reel tether to new eye block.

(24) Remove eye block from container with screws attached.

(25) Position eye block on electrical connector.

(26) Push eye block into place.

(27) Hand start eye block screws.

(28) Remove power tool from tool box.

(29) Attach screw driving tool on power tool.

(30) Position screw driving tool on screw.

(31) Tighten screw.

(32) Repeat steps (30) and (31) two times on remaining two screws.

(33) Place screw driving tool in tool box.

(34) Place power tool in tool box.

(35) Remove lens protective cover.

(36) Place cover in general purpose container.

(37) Remove reel tether.

(38) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Protective cover for eye block
- High torque driving tool
- Inert gas container
- Replacement fine eye assembly with electrical connector and attaching screws

POTENTIAL PROBLEM AREAS: Existing screws may not be removable without damage which would preclude attachment of new eye block.

8.3.7.9 Addition of Stabilization Torquing Coils

MISSION(S) 3

EXPERIMENT PRIORITY Secondary

PURPOSE AND OBJECTIVE: To add an electromagnetic torquing coil to the OSO satellite in order to improve the OSO performance, and thus add greatly to the scientific yield of the mission. This corrective measure will also aid in minimizing the expenditure of pitch gas due to interaction of the OSO with the earth's magnetic field.

OBJECT DESCRIPTION: An electromagnetic coil is incorporated into the OSO control system which can be energized/de-energized by command from the ground in order to counteract the interaction between the OSO and the earth's magnetic field. Depending on the nature and magnitude of this interaction, it may be desirable to incorporate another electromagnetic coil to aid the function of the existing coil. If desirable, an electromagnetic coil can be added to the back side of the OSO sail structure (BBRC drawing E8011).

PROCEDURE:

(1) Orient and lock wheel.

(2) Open storage container.

(3) Astronaut moves inboard.

(4) Release sail clamp.

(5) Position sail.

(6) Lock sail in position.

(7) Elevate platform.

(8) Attach reel tether to magnetic coil in storage container.

(9) Remove coil from storage container.

(10) Position coil on sail structure and clamp in place.

(11) Release reel tether.

(12) Release coil electrical harness from retainer.

(13) Connect coil harness connector into sail umbilical.

(14) Astronaut lowers platform to wheel height.

(15) Astronaut moves outboard.

SPECIAL TOOLS AND EQUIPMENT:

- Electromechanical coil with clamp, electrical harness, and connector
- Storage container

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8.3.8 Return to CM and Stowage of Materials

Refer to Section 6.3.8 for this mission operation which will be similar to Mission 1.

8.3.9 Release and Capture Mechanism Jettison

Refer to Section 6.3.9 for this mission operation which will be identical to Mission 1.

8.3.10 Post-Release Inspection

Refer to Sections 6.3.3.2 and 6.3.3.3 for these mission operations which will be identical to Mission 1.

8.4 EXPECTED SIGNIFICANT RESULTS

The major expected significant results for Mission 3 are:

- Evaluation of orbit transfer and techniques for rendezvous with a non-cooperative satellite
- Extensive evaluation of capture and release techniques and hardware
- Extensive evaluation of EVA technology
- Refurbishment of the target OSO in the following areas:

  a. Replenishment of the pitch and spin gas systems

  b. Addition of new batteries and solar array to correct for degraded power supply performance

  c. Addition of new tape recorders to correct for degraded performance

  d. Addition of new wheel and pointing control electronics to correct malfunction or improve reliability or performance

  e. Replacement of control sensor assembly to correct malfunction or improve reliability or performance

  f. Replacement of experiment optics or sensors to improve performance

  g. Maintenance of possible malfunction of elevation and arm locking systems

  h. Addition of magnets and torquing coils to improve stabilization characteristics

- Calibration of magnetometer
- Checkout of all refurbished functions
- Extensive EVA experience in performing useful work

8.5 INTEGRATED TIME LINE

The IVA and EVA times required to perform each task presented in Section 8.3 is summarized and integrated in a time line analysis for Mission 3 which is presented in Fig. 8-2.

8.6 TOOLS AND EQUIPMENT

The special tool and equipment requirements to conduct the experiments for ESMRO Mission 2 have been summarized in Table 7-3. A commonality usage of these tools is presented in the Tool Usage Chart, Table 7-4.

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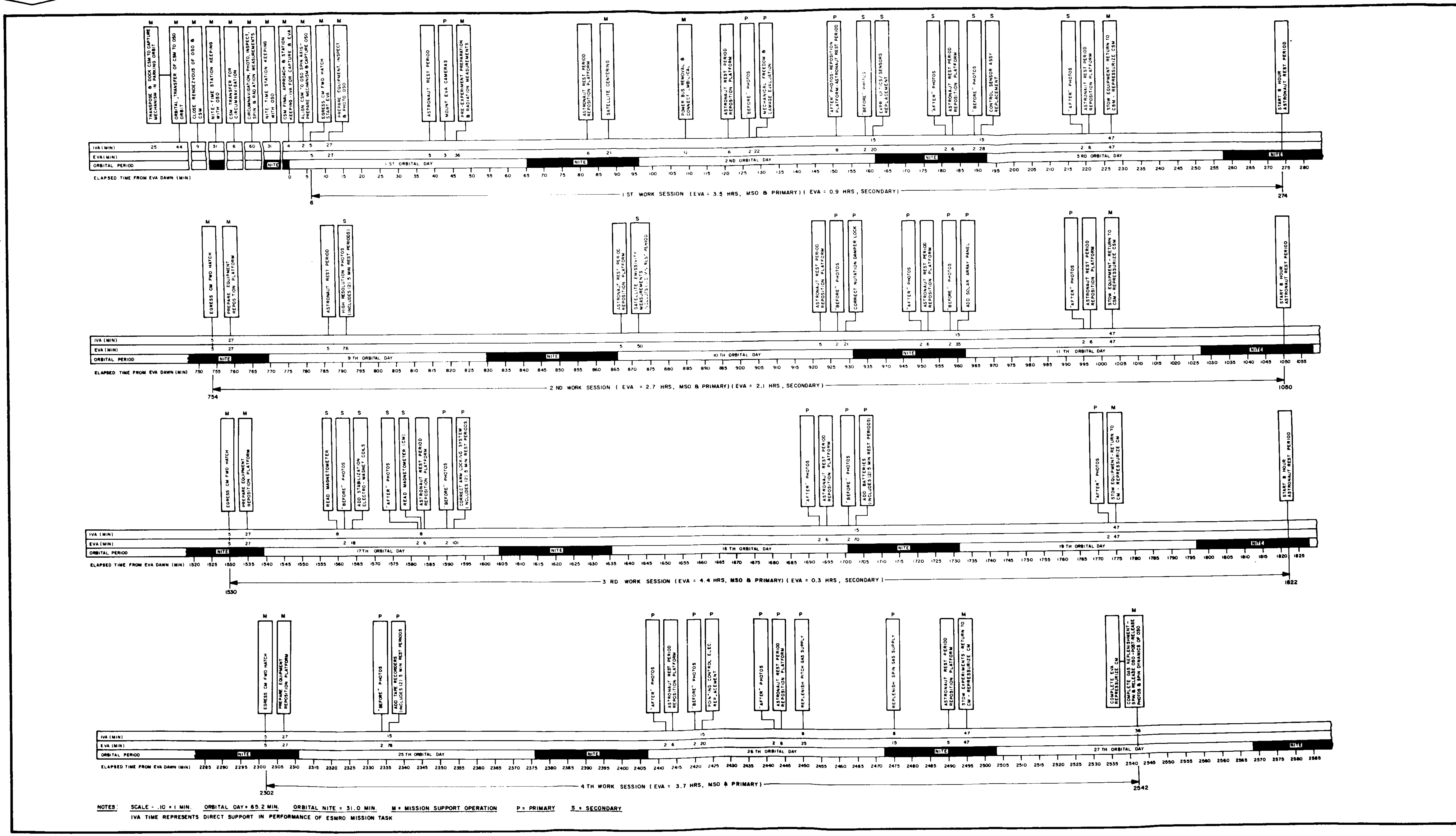

Fig. 8-2 Mission 3 Time Line Analysis

8-26-2

SECTION 9

REQUIREMENTS

Section 9
REQUIREMENTS

The major requirements for accomplishing each phase of an ESMRO mission are presented in this section. The requirements are presented for the major systems involved: (1) the CWP; (2) the CSM, (3) the OSO, and (4) the crew and mission operations. The requirements for the CWP are presented in terms of the major subsystems involved in the mission phases. For the CSM, OSO, and crew and mission operations, the requirements include the hardware modifications and operational procedures for each phase of the mission.

9.1 CAPTURE WORK PLATFORM

The CWP (Fig. 4-23) is to consist of subsystems required to perform the rendezvous, capture, useful work, and release phases of the mission. Each subsystem is discussed in the following sections.

9.1.1 Structure

The CWP structure consists of a central boom that supports the CSM/CWP docking mechanism and egress/ingress structure at one end; the CWP/OSO capture mechanism at the other end; and the work platform and associated support equipment along the central portion. The structural boom also contains a translation spring to absorb impact loads during satellite capture. Passive thermal control of the various mechanisms will be provided.

9.1.2 CSM/CWP Docking Mechanism

The CWP is to be stowed in the SLA region until the CSM separates from the S-IV B. At that time, the CSM should dock with the CWP using a standard CSM/LEM docking arrangement. A LEM type docking collar would be mounted on one end of the CWP boom.

After docking is completed, the CSM would remove the CWP from its stowed position in the SLA and initiate the ESMRO mission.

9.1.3 Egress/Ingress Structure

An egress/ingress structure is provided between the docking collar and CWP structural boom. This structure will provide the astronaut space and fixity for egress and ingress through the forward hatch as well as fixity for erection of the work platform.

9.1.4 Capture Mechanism

Capture of the target OSO is to be performed by maneuvering the CWP attachment head into contact with the OSO and then containing the OSO until dynamic equilibrium is achieved.

The capture mechanism is attached to the front end of the CWP boom; it consists of a flexible joint and an attachment head with a controlled spin axis. The flexible joint is located between the boom and attachment head, and it provides for free attachment head movement in pitch and yaw. Spin control of the attachment head is provided to match the spin dynamics of the OSO. The attachment head consists of either an adhesive ring or a three arm yoke; both types have a centering adjustment mechanism for aligning the OSO spin axis to the center line of the CWP boom. An electrical discharge probe is provided with the attachment head to equalize any possible OSO static charge.

The CWP spin axis control (astronaut controlled) is to brake the spin angular momentum of the OSO until it reaches equilibrium with the CSM. Once the OSO reaches this equilibrium, all three axes are locked. The centering of the OSO about the CWP spin axis is to be accomplished manually by the EVA astronaut. The adhesive ring or the three arm yoke is to be released in conjunction with centering the OSO.

To release the OSO from the CWP, the astronaut remotely operates the CWP spin control mechanism until the OSO spin control system is functioning. He then releases the restraining clamps of the centering mechanism. The CSM/CWP is slowly backed away from the OSO utilizing the CSM RCS thrusters.

9.1.5 Work Platform

The platform required for performing useful work is to be attached to the CWP boom. It folds next to the boom until the EVA astronaut egresses from the CM forward hatch, at which time he deploys the work platform. The major sections of the platform include a fixity brace and equipment stand that is to be manually erected perpendicular to the base of the work platform. The work platform base will erect automatically perpendicular to the boom, with the EVA astronaut tethered from the waist to the fixity brace and in foot restraints on the work platform base.

The base of the work platform must be movable in a radial direction from the boom, in order to move the EVA astronaut in and out with respect to the OSO. The entire work platform is to be capable of moving along the boom in order to move the EVA astronaut up and down with respect to the OSO. These translation motions are to be performed by the astronaut with a powered mechanism, that has a manual backup capability.

9.1.6 Power

CWP self-contained power will be required to operate the spin control mechanism and to release the attachment head from the OSO. The overall power consumption for these operations should be less than 50 watt hours.

The power requirements from the CSM for the useful work phase of the mission include the operation of the platform, power tools, cameras, adhesive release, and artificial illumination devices. The overall power consumption for these operations should be less than 1900 watt hours.

9.1.7 Data Handling

Data handling requirements consist of housekeeping data to be used by the astronaut crew in order to determine the CWP status or to be used for recording the CWP performance. The data handling subsystems will also distribute the OSO data signals to the CSM for interfacing with the CSM OCS.

9.1.8 Command Control

The CSM command control requirements include all automatic functions of the docking and release operations that are controlled by the IVA astronaut with a control console in the command module. These are:

- Spin-up of the CWP attachment head
- Spin-down of the CWP attachment head/OSO
- RF commands to OSO
- Gas replenishment
- Release of the OSO
- Release of the CWP

The CWP command control requirements include all automatic useful work functions controlled by the EVA astronaut with a control console mounted on the fixity brace. These are:

- Work platform release erection
- Work platform up and down movement
- Work platform in and out movement
- Spin control mechanism lock and release
- EVA camera operation
- Artificial light illumination
- Power on/off operation

9.1.9 Tools and Support Equipment

A variety of tools are required to perform the torquing wire, cutting and prying operations for the experiment tasks. The primary tool is to be a power tool, with adaptive heads for the different operations. Support equipment requirements include the cameras, gas supplies, lighting provisions, and selected instrumentation equipment for special experiment tasks.

9.1.10 Storage

The storage requirements for the capture/release phase of the mission include provisions for the entire CWP during ascent prior to CSM/CWP docking. The CWP envelope can be considered a cylinder 15 feet long and about 3-1/2 feet in diameter. It is recommended that the CWP be stored in the SLA during ascent; however, the CWP boom could be telescoped into the ingress/egress structure to reduce its overall length to less than 12 feet for storage in Sector I of the Service Module.

The storage of tools and new parts to be added to the OSO is to be in the compartments on the work platform. Containers for the recovered parts are to be initially located on the boom or work platform and then transferred to the CM for storage during return to earth.

9.2 COMMAND SERVICE MODULE

The CSM requirements for the various mission phases to perform the ESMRO mission are indicated in this section.

9.2.1 Rendezvous

The rendezvous of the CSM with the target OSO requires that the SM-SPS be used to provide about 406 mps (1330 fps) delta velocity. The CSM guidance and navigation system is to be used during the terminal guidance phase, along with crew operations utilizing a direct viewing sextent or reticle. Station keeping is to be performed by short thrust impulses of the CSM RCS to provide delta velocity in a given direction with respect to the OSO. Communications to the surface may be required for tracking update information during the initial phases of rendezvous.

9.2.2 Capture/Release

The CSM docks to the CWP using a CSM/LEM type docking system. The capture of the OSO by the CSM/CWP requires maneuvering control by the SM RCS to align the CSM to the OSO and to make contact with it.

After release of the OSO, the CSM backs away slowly using the RCS thrusters. The CWP is jettisoned by releasing the docking collar and backing the CSM away with the RCS thrusters.

A command control unit is to be located in the CM during these operations.

9.2.3 Useful Work

Attitude control of the CSM/CWP/OSO configuration is to be maintained by operation of the SM RCS during useful work operations. The CSM is to provide the power for the CWP during these operations. In-orbit checkout of the OSO is to be performed by the astronaut crew using the CSM on-board checkout system. The interfacing of power will be by means of an umbilical through the forward hatch. Commands and data signals between the CSM and CWP is to be accomplished by a hard line connection through the docking collar. Useful work will require the services of both the IVA and EVA astronauts and depressurization of the CM during each work session.

9.2.4 Storage

Storage space will be required in the Command Module for the return of materials and equipment to earth.

The containers for the smaller parts are to be stored in the rock boxes or in the food containers. The longer containers, such as those for the HCO instrument and the solar array, are to be stored in the CM aisleway under the center couch.

9.3 OSO

The requirements of the ESMRO mission on the target OSO's are given by mission phase in this section.

9.3.1 Rendezvous

The rendezvous and station keeping maneuvers can be performed without tracking cooperation from the target OSO's; therefore, there are no special requirements on OSO.

9.3.2 Capture/Release

The capture of a target OSO can be performed without cooperation from the OSO; consequently, there are no special requirements on OSO. Similarly the OSO can be released from the CWP without any cooperation. However, for the refurbishment missions, it is expected that the OSO's pointing and spin control, as well as other automatic systems will be operating prior to release.

9.3.3 Useful Work

The requirements of the ESMRO missions on the target OSO in the useful work phase of the mission vary, depending on the mission, and are given on the following page.

9.3.3.1 Mission 1 – Material Retrieval

There are no requirements that can be implemented on the OSO II target, since it is presently in orbit.

9.3.3.2 Mission 2 – Refurbishment

The target OSO candidates for this mission have passed their design freeze dates, and only minor modifications can be accomplished prior to their launch. Minor modifications that should be performed include changing connectors and screws that must be removed for access and entry of the new circuits and added parts. Analysis must be conducted to determine the design of parts to be added, and their fabrication test and checkout must be accomplished. Hand holds could also be added to the OSO to assist the EVA operations. Documentary photography should be initiated as soon as possible to provide configuration data of the specific OSO target satellite.

9.3.3.3 Mission 3 – Refurbishment

The advanced nature of this refurbishment mission requires that the OSO candidates be modified prior to launch. The suggested modifications include redesigned distribution of circuits to auxiliary connectors in close proximity to the parts to be added. Spare commands should be wired to strategic auxiliary connectors to permit the addition of new control features. Electronics to be replaced should be redesigned to facilitate easy access, removal, and installation under EVA conditions. Analysis must be conducted to determine the design of new parts to be added, and their fabrication test and checkout must be accomplished. Special purpose emissivity and high magnification measurements of selected surfaces require that good prelaunch control data be obtained. Documentation photography must be taken to provide configuration data of the specific OSO target satellite.

9.4 CREW AND MISSION OPERATIONS

9.4.1 Rendezvous

The major crew and mission operations involve the following steps:

(1) Dock with and remove CWP from SLA.

(2) Prepare for orbit transfer, and compute attitude and time.

(3) Perform the course orbit transfer propulsion.

(4) Perform mid-course transfer orbit correction.

(5) Visually acquire the target OSO at orbit dawn.

(6) Perform terminal rendezvous with target OSO by visual sightings and fine thrust impulses.

(7) Perform two night station keeping maneuvers.

(8) Perform one day time circumnavigation of the target OSO.

The training for the rendezvous phase should be similar to that used for visual rendezvous procedures during the Gemini program.

9.4.2 Capture/Release

The major crew and mission operations for OSO capture involve the following steps:

(1) Perform precapture inspection of the OSO.

(2) Align the CSM/CWP along the OSO spin axis.

(3) Translate the CSM/CWP into contact with the OSO.

(4) Contain the OSO until dynamic equilibrium is reached.

These operations should be performed during orbital daylight.

The major crew and mission operations for OSO release involve the following steps:

(1) Complete gas resupply operations.

(2) Align the CSM/CWP/OSO long axis perpendicular to the solar direction.

(3) Actuate the OSO automatic systems.

(4) Spin-up the OSO by means of the CWP spin control system until the OSO spin control is in operation.

(5) Activate the OSO pointing control until it is pointing at the sun.

(6) Release the attachment head.

(7) Separate the CSM/CWP from the OSO.

(8) Perform post-release inspection of the OSO.

(9) Jettison the CWP from the CSM.

The training requirements for this phase should include docking and release operations utilizing spinning OSO and a simulator that will react to the control forces similar to the in-orbit spinning OSO.

9.4.3 Useful Work

The major crew operations for performing useful work are presented in Tables 6-2, 7-2, and 8-2, with the respective EVA and IVA times indicated for the three missions. EVA activity is separated with eight hour rest periods between successive work sessions. Each work session includes short rests following periods of intensive EVA activity. The exact duty cycling of the work sessions will be determined by the overall AAP mission profile. The ESMRO portion of the AAP mission should require less than three calendar days to complete.

The training for the useful work phase will include both laboratory and underwater neutral buoyancy simulation using CWP/OSO mockups.

SECTION 10

REFERENCES

Section 10
REFERENCES

1. E. I. Lineberry, R. F. Brissenden, and M. C. Kurbja, Analytical and Preliminary Simulation Study of a Pilots Ability to Control the Terminal Phase of a Rendevouz with Simple Optical Devices and a Timer, NASA Technical Note D-965m, 1961

2. D. L. Zink, "Visual Experiences of the Astronauts and Cosmonauts," Human Factors, Vol. 5, No. 3, Jun 1963

3. A. Hymen, "Utilizing the Visual Environment in Space," Human Factors, Vol. 5, No. 3, Jun 1963

4. L. G. Summers, R.A. Shea, and K. Ziedman, "Unaided Visual Detection of Target Satellites," Journal of Spacecraft and Rockets, Vol. 3, No. 1, Jan 1966

5. U. F. Grether, "Visual Search in the Space Environment," Human Factors, Vol. 5, No. 3, Jun 1963

6. F. O. Vonburn, "Ground Tracking of Apollo," Astronautics and Aeronautics, Vol. 4, No. 5, May 1966

7. E. Harrison, "Rendevouz Energy Required for Collision and Pursuit Course Guidance," Advances in the Astronautical Sciences, Vol. 16, Part 1, 1963

8. LTV/Argonne Laboratory mid-term presentation to MSFC on 7 Nov 1966 (Re: current MSFC contract with AFC-ANL-Master Slave manipulators for space application)

9. Emerson Electric Company Contract AF33(615)–2546

10. BBRC, OSO E Reliability Analysis, TR66-64, by P. D. Hancock, Boulder, Colorado, 9 Aug 66

11. NASA Manned Spacecraft Center, Experiment MSC-2 Proton-Electron Measurements on Gemini IV, by J. Marback

12. Air Force Weapons Laboratory, Experiment D-8, Radiation in Spacecraft, Gemini IV, Kirtland AFB, New Mexico

13. NASA, Orbiting Solar Observatory Satellite (project summary), NASA SP57, 1965

14. BBRC, Final Report, S-16 Orbiting Solar Observatory, Boulder, Colorado, 1964

15. BBRC, Final Report, OSO B2 Orbiting Solar Observatory, Boulder, Colorado, 15 Sep 66

BBRC

16. GSFC, Satellite Situation Report, 15 Aug 66

17. BBRC, OSO B2 Vehicle Interface and Support Requirements, Boulder, Colorado, 10 Aug 64

18. R. W. Wolverton, Optical Operations, Rev. 1963

19. BBRC, OSO Dynamic Analysis, F66-06, by T. M. Spencer, 15 Nov 66

20. BBRC, ATM Study Report, Boulder, Colorado, 1 Apr 66

BBRC DRAWINGS

B7774	Cap-Pressure Seal Modified
C8318	Silicon Cell Assembly
C8383	Check Valve
D8333	Harvard R. P. T. Flex Print Cable
D8727	Harvard R. P. T. Assembly
D16410	Bracket-Ground Handling
E8010	Satellite Wheel Assembly
E8011	Upper Section Assembly
E7753	Servo Amplifier Assembly

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Appendix A
ORBITING SOLAR OBSERVATORY (OSO) DATA AND INFORMATION
(Prepared for the ESMRO Study Program)

A.1 INTRODUCTION

This document contains summary information pertinent to the Orbiting Solar Observatory (OSO) configurations for consideration with regard to the ESMRO study program. Where specific and detailed information is not presented, other documents have been referenced citing the information. The tables and figures give data for each orbiting configuration (i.e., OSO I and II), as well as OSO D and OSO E1, which are scheduled for launch in the near future, and OSO's F, G and H. The general configuration of the OSO is shown in Figs. A-1 and A-2.

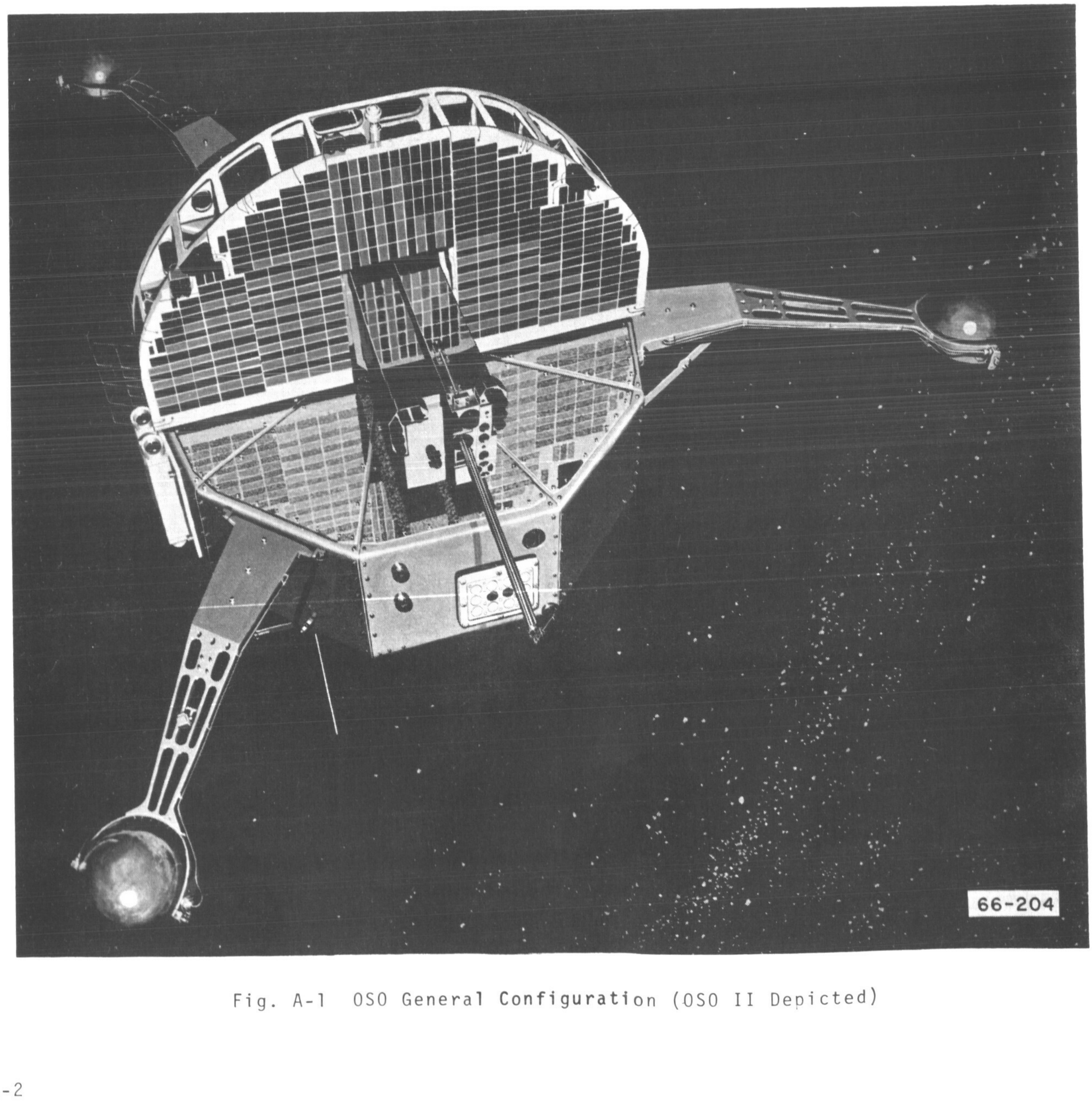
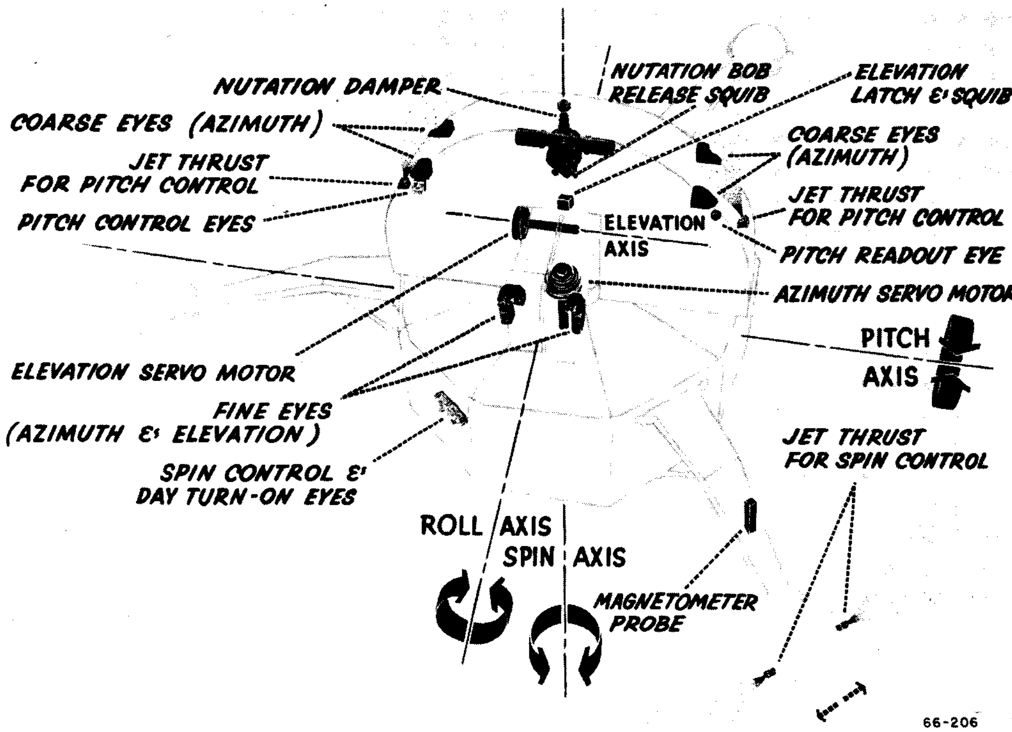


Fig. A-1 OSO General Configuration (OSO II Depicted)



A-2 OSO Major Features

A.2 ORBITAL INFORMATION

The OSO satellite is launched from Cape Kennedy by a Thor-Delta vehicle at a launch azimuth of 108 degrees, into a nominal circular orbit. Table A-1 gives the actual orbit parameters for OSO's I and II, and the programmed orbit parameters for OSO's D and E1 (Ref. 13, 14, 15, 16).

Table A-1
OSO ORBITAL PARAMETERS

Orbit Parameters	OSO I	OSO II	OSO D, E1 F, G, H
Apogee (km) (nm)	584 (317)	626 (340)	
Circular Perigee (km) (nm)	547 (297)	549 (298)	553 ± 92 (300 ± 50)
Period (min)	96.0	96.5	96
Inclination angle (deg)	32.83	32.85	33 ± 3
Launch date	3/7/62	2/3/65	N.A.

The OSO I and II orbit periods have not changed much to date, and so it can be concluded that they will still be in orbit by 1969 through 70 and 71. The orbit, being slightly elliptic, will decay by a lowering of the apogee until the orbit is near circular. Further decay will be a very slow spiral down to an altitude where drag will cause a sudden re-entry (Ref. 18). Orbit inclination will remain the same throughout the life time. The exact position for any day can be predicted in the years 1969 to 1971 and will be determined at the time of the CSM launch.

A.3 PHYSICAL CHARACTERISTICS

A.3.1 Mass and Inertias

Mass and inertia data for the various OSO configurations are listed in Table A-2.

Table A-2
OSO MASS AND INERTIA DATA

OSO	I	II	E1	D
Weight (lb)	450	542	620	587
MOI (slug ft^2)[a]	16.6	20.1	23.2	(c)
CG (in.)[b]	12.68	12.80	12.58	(c)

[a] The MOI is the total transverse moment in orbit configuration.
[b] The CG location given is the distance above the launch vehicle attach plane.
[c] Information was not available at the time of writing.

NOTE: Data for later OSO's will be similar.

A.3.2 Physical Details

The general configuration of the OSO is as shown in Fig. A-1. The OSO is comprised of a sail section, which is oriented toward the sun, and a spinning wheel section. The OSO wheel is a nonogon configuration; it is 10.4 inches high and has a maximum and minimum radii of 22 and 20.7 inches, respectively. Specific dimensions of a typical OSO are shown in Fig. A-3. The sail is 23.5 inches high, 40.4 inches across, and 6.2 inches deep. The pointed experiment package varies in length according to the type of experiments it incorporates. The pointed experiment package is typically 40 inches long, 8 inches high, and 8 inches wide. Some experiments have extendible parts which are projected a greater distance from the spin axis than the edges of the wheel (once orbit is achieved). Specific information on pertinent OSO subsystems can be obtained from the following drawings listed in Table A-3.

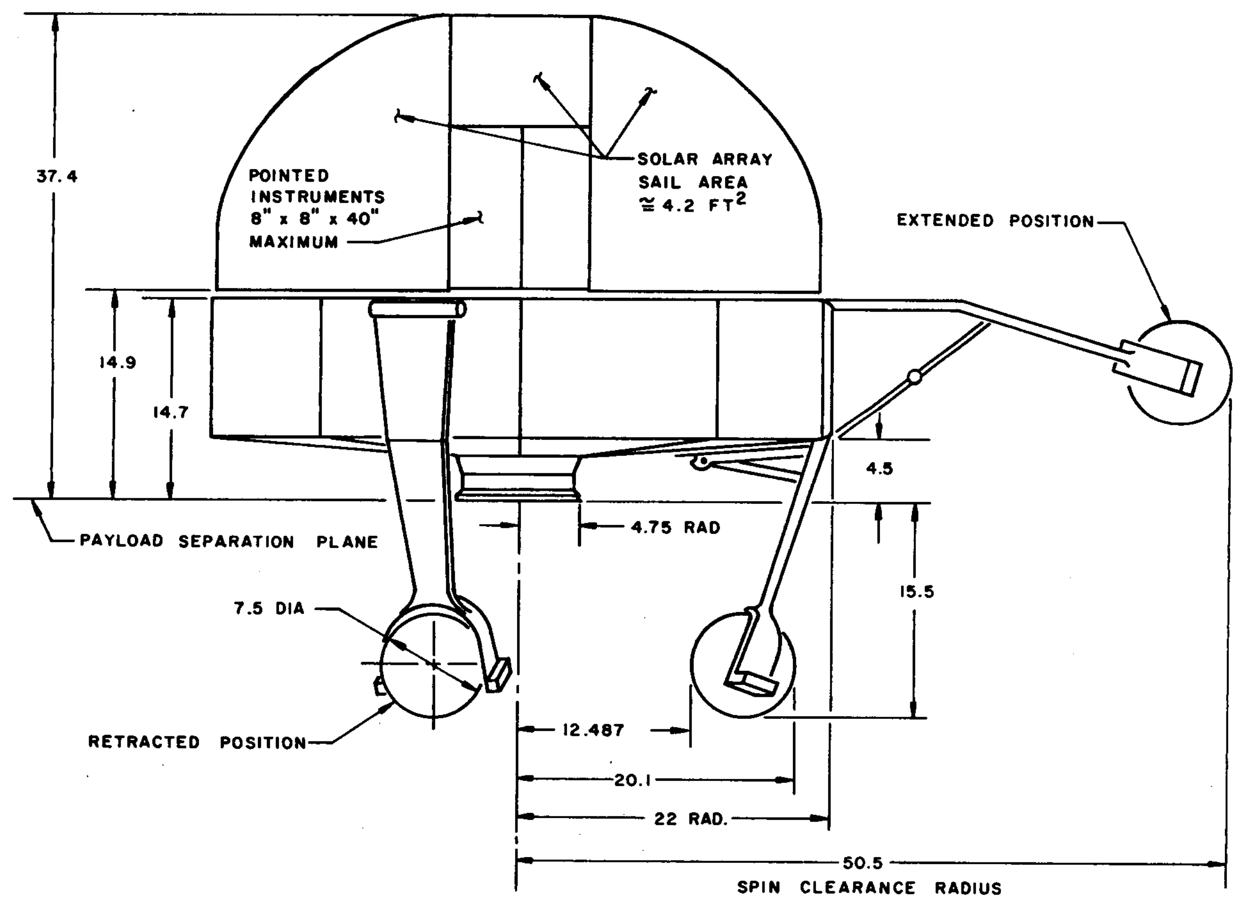


Fig. A-3 Typical OSO Dimensions

Table A-3
OSO DRAWINGS

Drawing No.	Title
15689	Configuration Drawing OSO D
19291	Structure Assembly - Wheel
19292	Fitting Attachment/Separation
19302	Structure Assembly - Sail
19538	Pneumatics Installation Spin Gas
19539	Pneumatics Installation Pitch Gas
19540	Observatory Assembly
19541	Spacecraft Assembly
19564	RF Systems Installation

A.3.3 External Surfaces and Materials

The OSO is a composite of numerous materials and surfaces. Material alloys and coatings for all major exposed surfaces are as listed below in Table A-4.

Table A-4
OSO MATERIALS AND COATINGS

Component	Alloy	Coating
Arms	2024-T351 Al	Satellite aluminum paint (80 μ)
Rim panels	6061-T6 Al	Satellite aluminum paint (80μ)
Covers	Bondolite Honey-comb panels	Bare
Castings	A356 Al	Bare and satellite white paint (63 w)
Gas bottles	6 Al - 4 v Ti	Bare
Sail	2024 - T42	Satellite white paint (63 w)
Wheel formed parts	6061 Al	Bare
Epoxy strips	Nema G-11	Bare
Aluminum strips	2024-T3	Bare

A.3.4 Radioactive Sources

Depending on the scientific experiment configurations, the OSO contains a variety of radioactive sources. Table A-5 presents a summary of the radioactive sources for the different OSO configurations (Ref. 16 and 17).

Table A-5
OSO RADIOACTIVE SOURCES

Experiment	Source	1962	Half Life	1970 (Predicted)
OSO I	No Sources			
OSO II				
GSFC UV	Strontium - 90 (Sr^{90})	5 microcuries	28 yr	4.1 microcuries
Univ. of Minn.	Carbon - 14 (C^{14})	1000 microcuries	5770 yr	999 microcuries
NRL	Iron - 55 (Fe^{55})	10 microcuries	2.7 yr	2.8 microcuries
(These sources are shielded, and are not detectable with external measuring equipment.)				
OSO D				
UCL	Iron - 55 (Fe^{55}) (quanity 3)	100 microcuries (each)	2.7 yr	28 microcuries (each)
	Iron - 55 (Fe^{55}) (quanity 2)	250 microcuries (each)	2.7 yr	70 microcuries (each)
	Iron - 55 (Fe^{55}) (quanity 2)	500 microcuries (each)	2.7 yr	140 microcuries (each)
ASE	Iron - 55 (Fe^{55})	150 microcuries	2.7 yr	42 microcuries
LRL	Promethium - 147 (Pm^{147})	10 microcuries	2.5 yr	2.5 microcuries
(These sources are shielded, and are not detectable with external measuring equipment.)				
OSO E1	No Sources			
OSO's F, G, and H	No Significant Sources Planned			

A.4 PERFORMANCE

A.4.1 General

OSO is a spin stabilized satellite. Dumping or transferring the spin angular momentum associated with rotation of the satellite bodies is the principal problem in the ESMRO capture operation. The magnitude of this spin momentum and its distribution among the wheel, the sail, the pointed experiment package, and the nutation damper are all dependent upon the operational status of the satellite control systems. Thus, the nature of the capture problem depends largely upon whether or not the control systems are operating (or operative).

The status of the spin control system is the paramount factor in determining the nature of the capture problem. The total momentum of the satellite is largely determined by whether or not the spin control system has remained operative from launch to the time of encounter with the capturing spacecraft. If the spin control system has failed, then the mode of failure largely determines the satellite momentum at the time of encounter for capture. On the other hand, an operative OSO spin control system has built-in command capability which makes possible a cooperative capture in which it is only necessary for the capturing spacecraft to command a series of despin bursts; this essentially reduces the OSO spin momentum to zero. In this latter case, the principal problem in the capture operation would be eliminated.

The initial step in the ESMRO capture operation, that of "grabbing hold" of some part of the OSO, is simplified if that step is performed when the upper structure is oriented (e.g., assuming the azimuth control system is operative and the capture operation is initiated during spacecraft day). In this case, the nonrotating sail would be easy to grab. The problem of attaching a capture and despin device to the third stage attachment flange on the bottom of the OSO, would be simplified somewhat if the upper structure were oriented; this is due to the fact that relatively loosely controlled upper structure mass unbalances would not cause wobble. The wheel spin momentum represents the entire satellite spin momentum in this case.

In view of the potential importance of the OSO control systems to the capture operation, these systems are described in considerable detail in this appendix. Also, the dynamics properties of OSO are described; these should be considered if OSO is to be captured and stabilized by another spacecraft while in orbit. (Further information on the dynamics of an OSO satellite can be obtained from Ref. 19.)

A.4.1.1 Momentum Distribution, Satellite Day

Should the OSO be captured while engaged in normal daytime operation, then its entire spin momentum would be very nearly associated with rotation of the wheel about the intended spin axis. Mass unbalances in the wheel are tightly controlled (the principal axis of inertia must be within 1 minute of the intended spin axis), and the nutation damper operates after satellite dawn to quickly reduce nutation to an amplitude of less than an arc minute. In normal daytime operation, the wheel spin rate varies between 0.5 and 0.66 rpm as a result of the control limit of the spin control system. The wheel spin momentum is, thus, between 95 and 125 ft-lb-sec.

A.4.1.2 Satellite Night, Spin Control System Operating

If the OSO is captured while engaged in its normal night time operation, (either because capture occurs during satellite night, or because the satellite control systems are commanded off), then the total satellite momentum is divided between the upper and lower structure. The spin rate of the wheel is lower in this case (between 0.44 and 0.56 rps), and there is much more wobble and nutation than is present during daytime operation. Thus, either the upper or lower structure could be "grabbed" during the capture operation, and its spin momentum could be dumped separately from that of the other structure, so long as the azimuth bearing has not seized. The spin momentum of the "ungrabbed" structure would be slowly dissipated (in approximately 2 minutes) due to friction in the azimuth bearings, if bearing operation is normal. In this case, the wheel spin momentum is between 85 and 112 ft-lb-sec, while the sail spin momentum is between 10 and 13 ft-lb-sec.

The upper structure spins at the same rate as the wheel during night time operation and is also affected by wobble and nutation. The pointed experiment package assumes a position in which the minor moment of inertia axis is nearly perpendicular to the satellite spin axis. Nutation and wobble of sufficient amplitude will cause the experiment package to move in the elevation bearing. The nutation damper is forced against the wall of the damper case because of the centrifugal force associated with the sail spin rate. The damper thus has the affect of producing a mass unbalance of 0.40 in.-lbs.

The wobble and nutation present during satellite night are a function of the period during which the upper and lower structures have been spinning together. The mass unbalance allowed for the entire satellite (including the nutation damper bob offset and the relatively large maximum unbalances allowed in the pointed experiment package during orbital operation) is such that the major principal axis of inertia is within 10 arc minutes of the intended satellite spin axis. No OSO is presently scheduled which will have the maximum allowed unbalance. If the satellite has been in night time operation long enough, it will reach a steady-state condition in which the spin momentum vector is aligned with the principal axis of inertia. In this steady-state condition, a pure wobble of not more than 10 arc minutes will be present. If the satellite has not been in night time operation long enough to reach the aforementioned steady-state condition, then a transient condition may exist in which a combination of wobble and nutation of several times the steady-state amplitude is possible. This transient condition is characterized by a beat frequency between the spin and nutation frequencies. This beat frequency occurs because mass unbalances have the affect of applying a moment (rotating at the spin frequency) to the satellite.

A.4.1.3 Capture After a Period of No Spin Control

There is no exact date beyond which the OSO spin control system is expected to cease to function. The probability is high that the spin control system will function properly for a period on the order of 5 years. The OSO II spin control system is still functioning after a year and a half of operation.

If it is hypothesized that the spin control system failure occurs in such a way that no further spin control bursts occur, or if the OSO is ground-commanded off, then its spin rate will slowly decay due to external torques. The principal cause of spin rate decay are eddy currents in the satellite structure induced by the earth's magnetic field. Observations on OSO II indicate a secular spin rate decay of about 2 percent per month. This would result in a spin momentum reduction to about 80 percent of nominal after a year of no spin rate corrections. The spin momentum and spin rate would be reduced to about one-third of nominal after 5 years of no spin rate corrections. Thus, even after 5 years, the OSO would behave like a relatively rigid gyro.

A.4.1.4 Putting OSO Back Into Operation

Assuming electric power capability, the spin burst command capability should make it relatively easy to return OSO to normal operation. The principal problem will be to orient the intended satellite spin axis within ±15 degrees of perpendicular to the solar line of sight before or after the first 10 second spin-up burst is commanded. If this problem can be solved, the automatic operation of the spin control system will bring the spin rate up to the proper value, and all other automatic control systems will be able to function properly.

A.4.2 Control System

The OSO is a spin stabilized satellite consisting of two main sections: the wheel and the upper structure. The upper structure is connected to the wheel by the azimuth shaft and bearings which allow relative rotation of the two structures. The upper structure consists of two principal structures; the fan-shaped array or sail, and the pointed experiment package. The pointed experiment package is connected to the sail by the elevation casting and bearings which allow relative rotation of the sail and pointed experiment package about an axis which is perpendicular to the azimuth bearing axis.

OSO uses the gyroscopic properties of the spinning wheel for stability. The OSO inertial coordinate system is presented in Fig. A-4. Three spherical spin gas containers are sup supported by arms connected to the wheel and extended during orbital operation to increase the spin axis moment of inertia of the wheel (and, therefore, the inherent stability of the satellite). Spin gas jets are located at the ends of the arms. These jets are actuated by a signal from photodetectors and an electronic control system which computes the instantaneous period of rotation of the wheel with respect to the sun. The spin control system maintains the wheel spin rate during the spacecraft day within about -0 to +30 percent of the design rate of 0.5 rps. The spin control system is also used to reduce the spin rate of the spacecraft and the expended third stage of the launch vehicle from about two revolutions per second to the design spin rate prior to initial solar acquisition.

The biaxial pointing control system of OSO uses the entire vehicle as a controlled platform. Coarse elevation positioning of the stabilized section is accomplished by sensing pitch error with pitch control photodetectors and controlling pitch attitude with on/off jets. By exhausting nitrogen gas through nozzles mounted on the sail section, torques of either sense normal to the plane of the solar array can be produced to precess the spacecraft spin axis about the elevation bearing axis. The spin axis, thus, is positioned perpendicular to the solar line of sight within about ±3 degrees. There is no roll control about the solar line of sight, but rates around this axis are very slow.

Fine elevation and azimuth positioning of the pointed experiment package is accomplished by electrical servo motor control. The elevation torque motor is mounted on the casting which supports the pointed experiment package. This motor drives the pointed experiment package relative to the sail for fine positioning in elevation. The azimuth torque motor is mounted to the shaft connecting the stabilized upper section to the spinning wheel.

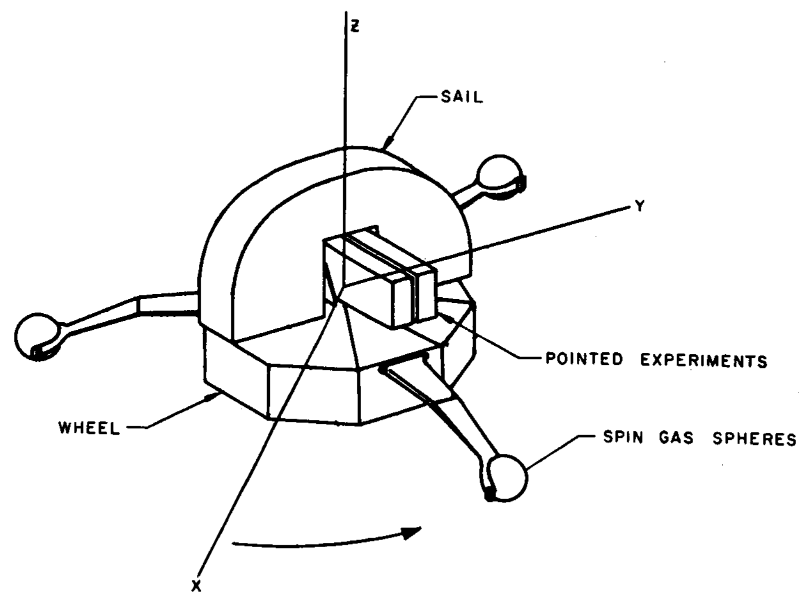


Fig. A-4 OSO Inertial Coordinate System

The azimuth and elevation servo motors are actuated by signals from two types of photo-detectors mounted on the stabilized upper section: (1) coarse detectors mounted on the sail structure; and (2) fine detectors mounted directly to the pointed experiment package. There are four coarse detectors. Each has a 90 degree field of view and gives a full 360 degrees of position control about the spacecraft spin axis. Shields provide an unobstructed view of the sun for elevation angles of ±15 degrees. The purpose of these shields is to limit the coarse eye view of the sunlit earth and to control the effect of reflections off portions of the satellite which could cause erroneous signals. There are two sets of fine detectors on the pointed experiment package which provide a differential signal over about

5 degrees in each direction from the solar vector.

When the spacecraft is in sunlight and the upper section is spinning, the azimuth coarse detectors provide a signal to the azimuth servo drive system, which despins the upper section. As the upper section spin rate is reduced to zero, the coarse detectors point the oriented experiments to within 2 to 3 degrees of the solar line of sight. At this time, a disabling detector mounted on the pointed experiment package actuates a relay which turns the coarse detector control off and fine detector control on.

The pitch control detectors are detection units for the pitch jet control system. This block of four detectors is mounted facing the sun on the front of the stabilized structure. Whenever the spin axis of the spacecraft drifts in pitch more than ±3 degrees from the normal to the solar vector, one of these detectors turns on the appropriate jet to precess the spacecraft back toward the desired position. Two of the detectors are needed for this function, one of either sense. The other two detectors turn off the jets whenever the spacecraft attitude has been returned to within 1 degree of the desired position.

Other photodetectors used in the pointing control system are a pair of turn-on/spin control detectors. One function of these detectors, as the name implies, is to actuate electrical equipment (turned off in the dark) each time the satellite emerges from the earth's shadow. The turn-on detectors double as spin control detectors. These detectors observe the sun once per wheel revolution, providing the spin controller with information for the determination of wheel spin rate.

A nutation damper is included to reduce OSO nutation amplitude to less than 1 arc minute during satellite day operation. OSO nutation, at orbit injection, is caused by mass unbalance and thrust misalignments during launch and by nonaxial components of the force exerted by the third stage separation spring. OSO nutation, during orbital operation, is caused by mass unbalances in the wheel and upper structure, by pitch gas precession torque, and by elevation servo torque. The nutation damper is mounted on the sail along the azimuth axis. The damper consists of a tuned spherical pendulum which moves in the silicon oil. The frequency of the pendulum, determined by bob mass, the spring constant and length of the suspension wire, is tuned to coincide with the nutation frequency (at the design spin rate). The damping constant is small so that the bob moves through large amplitudes for small nutation amplitudes. The damper is very effective for nutation amplitudes small enough that the bob does not hit the walls of the container (less than about 0.25 degrees), and for nutation frequency near that for which the damper is tuned.

During normal satellite operation, the spin control system commands spin bursts to spin the wheel either up or down. These bursts are of 4 seconds duration and are commanded only if the calculated spin rate is below 0.44 rps or about 0.66 rps. Spin-up bursts normally occur at satellite dawn after the control systems have been activated, but before the sail has acquired the sun (when the wheel spin rate is at the low night time value). Spin-down bursts are only required due to periodic spin rate variation caused by interaction between the satellite spin axis dipole moment and the earth's magnetic field. The spin control system can be ground-commanded to provide 4 second bursts in either sense (i.e., spin-up or -down) and can be deactivated (OSO I is an exception).

The pitch control system normally commands thrust, from the appropriate jet (of a pair of pitch control jets) mounted on the OSO sail. This thrust produces a moment about the OSO roll axis which causes pitch precession in the appropriate sense. Since symmetric pairs of pitch control jets are not used, a small translation acceleration is also generated by pitch control bursts. Four second bursts of either sense (i.e., pitch-up or -down) can be commanded from ground, but the sail must be oriented for these bursts to be effective. A four second burst produces a translational velocity change of 0.01 fps.

The azimuth and elevation control systems use DC torque motors which drive the sail and pointed experiment package so that the latter points at the sun. When the azimuth and elevation servos are deactivated (e.g., during satellite night when the turn-on detectors deactivate all control systems, or by ground command), the elevation and azimuth bearings transmit frictional moments. The moment transmitted by the elevation bearing acts between the sail and pointed experiment package to oppose relative motion. This moment is computed as

$$M_{FE} = T_{FE} + K_{DE}\dot{\varepsilon}$$

where

M_{FE} = elevation bearing frictional moment

T_{FE} = coulomb friction

K_{DE} = viscous friction due to back emf

$\dot{\varepsilon}$ = rate of pointed experiment package motion in the elevation bearing

The equivalent constants for the azimuth frictional moments are T_{FA} and K_{DA}. The freedom of elevation motion of the pointed experiment package is limited (± 5 degrees) by rubber stops with a coefficient of restitution of about 0.5.

The azimuth and elevation bearings transmit frictional torque, depending on the sense and magnitude of the relative rotation rate of the bodies they connect. The constants which describe these torques are

T_{FE} = 0.023 ft-lb

$K_{DE} = \dfrac{0.015 \text{ ft-lb-sec}}{\text{rad}}$

T_{FA} = 0.12 ft-lb

$K_{DA} = \dfrac{0.045 \text{ ft-lb-sec}}{\text{rad}}$

A.4.3 Dynamics

Dynamic properties of the OSO are described from the standpoint of capture and stabilization. For this purpose, the OSO can be viewed as a collection of four appropriately hinged rigid bodies. The dimensions, masses, inertias, and rotation rates of these rigid bodies are given herein, together with a description of the interconnecting hinges.

A.4.3.1 Definitions

Spin Momentum. The total angular momentum of a spinning orbiting body is the sum of the angular momentum associated with motion of the satellite about the earth in the orbit and rotation of the satellite body (bodies) with respect to an orbiting coordinate system which maintains attitude reference with the stars. The latter quantity is referred to herein as the spin momentum of the satellite.

Nutation. Nutation is used in the modern (although not universally accepted) sense employed in aerospace engineering. Both free body precession and the nodding of the spin axis of a gyroscope due to external torque are described here as nutation.

Wobble. In the case of a spinning body, which has assumed the minimum energy condition in which the motion is pure spin about the axis of major principal moment of inertia, wobble is the motion of that geometrical line within the body which was intended to be its spin axis. In the case where this minimum energy state has not yet been assumed (just after an unbalanced OSO sail spins up for example), the motion is very complicated and is referred to herein as a combination of wobble and nutation.

A.4.3.2 OSO Mathematical Model

The wheel is treated as a rigid body of revolution. The wheel could be treated as a body of more general shape without serious complication, but no loss of generality results from this assumption. The wheel spin moment of inertia about the axis of symmetry is I_s. The wheel transverse moment of inertia about any axis which passes through the wheel center of mass and is normal to the spin axis is I_t. The mass of the wheel is m_1, and d_1 is the distance from the center of mass of the wheel to the center of mass of the satellite. The center of mass distribution is as illustrated in Fig. A-5.

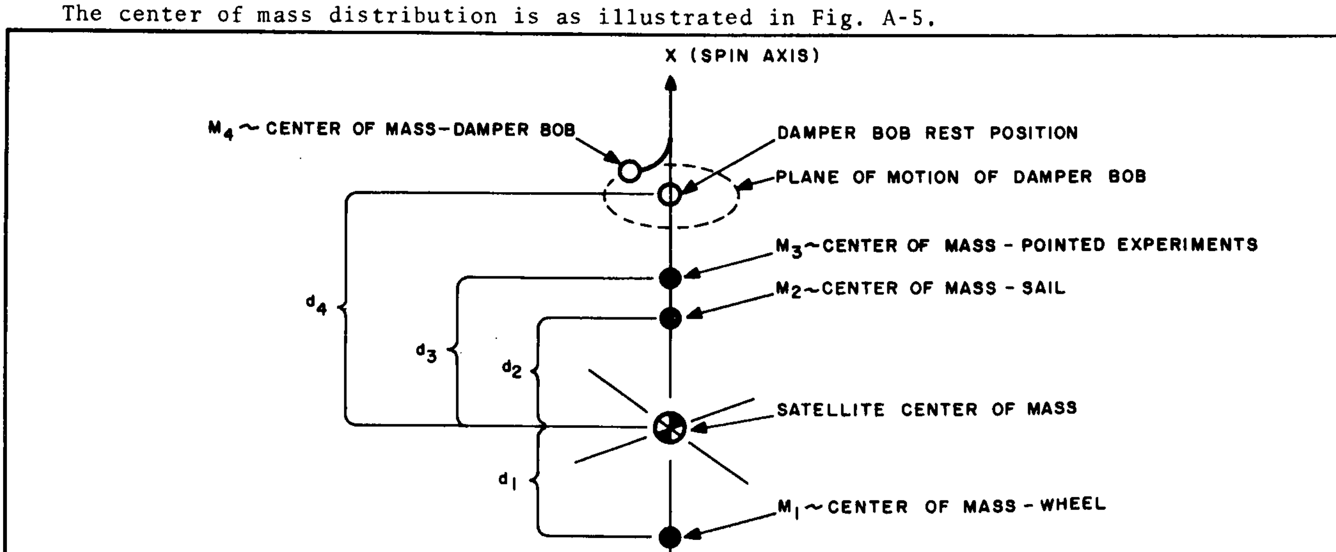


Fig. A-5 Center of Mass Distribution

The sail is treated as a rigid body which is attached to the wheel by a rigid shaft. The shaft allows relative rotation of the wheel and sail about the satellite spin axis. The moment of inertia of the sail about the axis normal to the spin axis (azimuth shaft axis), parallel to the plane of the solar array, and through the center of mass of the sail is I_{x_2}; I_{y_2} is the moment of inertia of the sail about the axis normal to the satellite spin axis, perpendicular to the plane of the solar array, and through the sail center of mass. The spin axis moment of inertia of the sail is I_{z_2}; m_2 is the mass of the sail and d_2 is the distance from the center of mass of the sail to the center of mass of the satellite.

The pointed experiment package is treated as a rigid body, which is attached to the sail by a rigid casting and by bearings that allow relative rotation of the pointed experiment package and sail about the elevation bearing axis. The elevation bearing axis is normal to the satellite spin axis and parallel to the plane of the solar array. The center of mass of the pointed experiment package is near the intersection of the OSO spin axis, the elevation spin axis, and elevation bearing axis. The pointed experiment package is carefully balanced only during the ascent to orbit. After the orbit is achieved, relatively large mass offsets (unbalances) are allowed and anticipated in the case of certain experiments which have moving parts. The moment of inertia of the pointed experiment package about the elevation bearing axis I_{x_3}, and I_{y_3} is the minor principal moment of inertia of the pointed experiment package. This moment is about the axis which is aligned with the solar line of sight during pointing. The moment of inertia, I_{z_3}, of the pointed experiment package is about the perpendicular to the X_3 and Y_3 axes. Motion (of the pointed experiment package about the elevation bearing axis) is constrained to a range of about ± 6 degrees by rubber stops. The mass of the pointed experiment package is m_3 , and d_3 is the distance from its center of mass to the center of mass of the satellite.

The nutation damper case and the damping fluid are treated as part of the sail. The nutation damper bob is treated as a point mass which moves, relative to its rest position, in a plane perpendicular to the satellite spin axis and fixed in the sail. The relative motion of the bob in this plane is assumed to result from the following forces: (1) a driving force which results from motion of this plane with respect to inertial coordinates; (2) a restoring force (in this plane) proportional to the distance from the bob to its rest position and directed toward the rest position; and (3) a viscous retarding force (in this plane) proportional to the velocity of the bob with respect to its rest position and directed to oppose the velocity of the bob with respect to its rest position. The mass of the damper bob is m_4; d_4 is the distance from the rest position of the bob (which is assumed to be on the satellite spin axis) to the satellite center of mass; k_4 is the spring constant associated with the restoring force mentioned in (2) above; and c is the viscous damping constant which retards relative motion of the bob.

A.4.3.3 Basic Mass and Geometry Numbers (OSO D)

The satellite mass at orbit injection is 18.5 slugs. The mass of pitch and spin control gas is 0.27 slugs. In the table below, a full load of control gas is assumed.

Table A-6
OSO MASS PROPERTIES

Wheel	m_1 = 12.15 slugs d_1 = 0.334 ft I_s = 30.4 slug-ft^2 I_t = 17.2 slug-ft^2
Sail	m_2 = 2.59 slugs d_2 = 0.714 ft I_{x_2} = 1.2 slug-ft^2 I_{y_2} = 1.8 slug-ft^2 I_{z_2} = 1.1 slug-ft^2
Pointed experiment package	m_3 = 3.07 slugs d_3 = 0.718 ft I_{x_3} = 2.5 slug-ft^2 I_{y_3} = 0.3 slug-ft^2 I_{z_3} = 2.5 slug-ft^2
Nutation damper bob magnification factor	m_4 = 0.026 slugs d_4 = 1.63 ft = 5 at 0.65 Hz (the damper natural frequency)

A.4.3.4 Moment of Inertia Ratios for OSO D

If it is assumed that the arms are extended and that a full load of spin gas is present, then only a small fraction of the spin gas is required for a normal OSO mission. The OSO can move as though it has four different moment of inertia ratios (and, therefore, four different nutation frequencies). There is the possibility that the sail is either oriented (i.e., for normal operation during satellite day) or spinning (satellite night or following completion of normal operation). It is possible for the elevation bearing to be free (as described for normal operation) or frozen as a result of seizing after extended operation.

The following moment of inertia ratios are possible for OSO D (the nutation frequency is the product of the moment of inertia ratio and the spin rate of the wheel):

(1) Normal daytime operation $\frac{I_s}{I_1} = 1.31$

(2) Normal night time operation

$$\frac{I_s + I_{z_2} + I_{z_3}}{I_1} = 1.47$$

(3) Daytime operation (elevation bearing frozen)

$$\frac{I_s}{I_1 + I_{x_3}} = 1.18$$

(4) Night time operation (as above)

$$\frac{I_s + I_{z_2} + I_{z_3}}{I_1 + I_{x_3}} = 1.32$$

where

I = total transverse moment

$$= \sqrt{\left(\sum_{i=1}^{4} m_i d_i^2 + I_t + I_{x_2}\right)\left(\sum_{i=1}^{4} m_i d_i^2 + I_t + I_{y_2} + I_{y_3}\right)}$$

$$= 23.17 \text{ slug-ft}^2$$

A.4.4 Status of Electronics and Power System

A.4.4.1 OSO I (Launched 7 Mar 1962)

The solar array power output has degraded about 25 percent. This is an estimate since the satellite was not provided with means for monitoring the solar array power. The excessive power degradation was due primarily to the artificial radiation belt established by the Starfish experiment. The batteries have apparently performed satisfactorily since launch. There is always the possibility that the continuous thermal cycling will break solder joints connecting cells together resulting in open circuits. Each open circuit would cause about a 3 percent power loss.

A.4.4.2 OSO II (Launched 3 Feb 1965)

The power output of the solar array has degraded about 10 percent during the first six months in orbit, and the main battery has shown evidence of high impedence.

A.4.4.3 Future OSO's

The power supply systems of future OSO's should behave in the same manner as has the OSO II power supply. The design of the power systems are essentially the same. Additional and better tests performed on the parts have increased confidence that the power subsystems will meet its design objective.

A.4.5 Communication Frequencies

Table A-7 lists the communication frequencies for command signals and telemetry for OSO's I, II, D and E-1.

Table A-7
COMMUNICATION FREQUENCIES

	OSO I (MHz)	OSO II (MHz)	OSO D (MHz)	OSO E1 (MHz)
Command	Classified	122.9	149.52	149.52
Telemetry	136.74	136.71	136.71	136.29

A.4.6 Status of Scientific Experiments

A.4.6.1 OSO I

There were no indications of major failure as of February, 1964, when the spacecraft was shut down.

A.4.6.2 OSO II

Failures were recorded on OSO II experiments as follows:

- HCO failed on turn-on
- NRL-RT failed approximately orbit 1500
- NRL-TAC failed approximately orbit 500
- GSFC-UV failed approximately orbit 3000

The remainder of the experiments were operable to orbit 4100 when the spacecraft was shut down.

OSO II was turned on again on 1 Jun 1966 to 5 Jun 1966. The experiments which were operable at orbit 4100 still operated and produced data.

Appendix B

OSO RENDEZVOUS PROGRAM

OBJECT: The initial position of the CSM is given by $\vec{P}_1$. The position of OSO at the end of the rendezvous is given by $\vec{P}_2$. The arc connecting $\vec{P}_1$ and $\vec{P}_2$ is the transfer trajectory. (See Fig. B-1.) The program will calculate the time to transfer and the ΔV requirements for selected positions of $\vec{P}_1$ and $\vec{P}_2$ and semimajor axes of the transfer ellipse.

CSM

a_1	Semimajor axis
e_1	Eccentricity
i_1	Inclination
Ω_1	Longitude of the node
ω_1	Argument of perigee
M_1	Mean anomaly

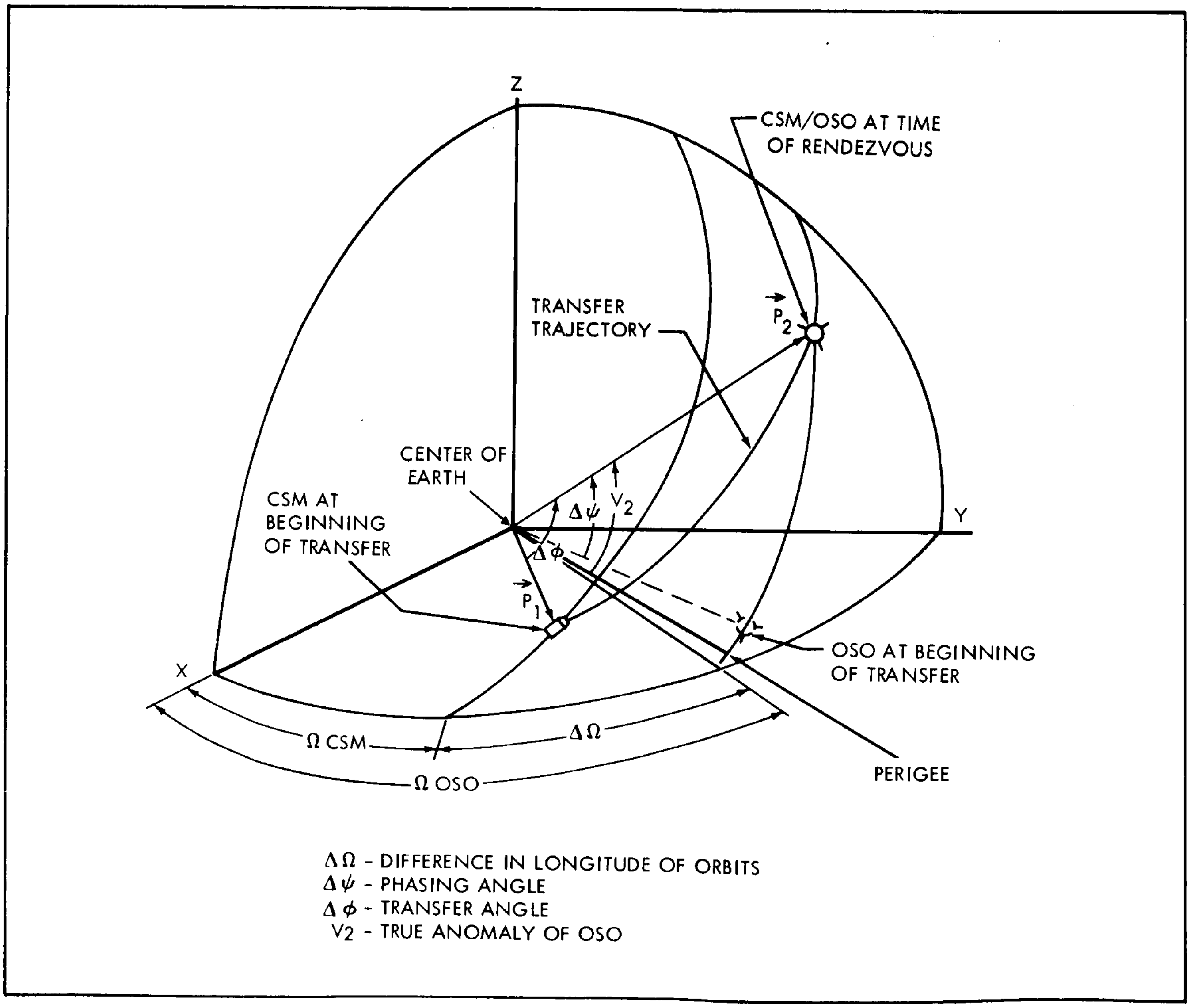


Fig. B-1 Rendezvous Out of Plane

OSO

a_2	Semimajor axis
e_2	Eccentricity
i_2	Inclination
ω_2	Argument of perigee

Scale Factors

SL	Large scale factor
SS	Small scale factor

Limits

V	Maximum ΔV permitted
L	Maximum range of Ω_2

The writeup contains the derivation of the equation. Only the equations preceded by a star are to be programmed.

Vary $\Delta\Omega$ for each set of initial conditions so that $\Delta\Omega = 0°(10°)L$. For these calculations, let L = 260 degrees. In each case

$$* \quad \Omega_2 = \Delta\Omega + \Omega_1$$

Vary V_2 for each set of initial conditions so that $V_2 = 0°(10°)360°$. Convert V_2 to radians for the calculations.

The vector $\vec{P}_1$ and $\dot{\vec{P}}_1$ are calculated only once.

$$* \quad \begin{cases} \ell_{11} = \cos \Omega_1 \cos \omega_1 - \sin \Omega_1 \sin \omega_1 \cos i_1 \\ m_{11} = \sin \Omega_1 \cos \omega_1 + \cos \Omega_1 \sin \omega_1 \cos i_1 \\ n_{11} = \sin \Omega_1 \sin i_1 \end{cases}$$

$$* \quad \begin{cases} \ell_{21} = -\cos \Omega_1 \sin \omega_1 - \sin \Omega_1 \cos \omega_1 \cos i_1 \\ m_{21} = -\sin \Omega_1 \sin \omega_1 + \cos \Omega_1 \cos \omega_1 \cos i_1 \\ n_{21} = \cos \omega_1 \sin i_1 \end{cases}$$

$$* \quad b_1 = a_1(1 - e_1^2)^{\frac{1}{2}}$$

Kepler's equation

$$M_1 = E_1 - e_1 \sin E_1$$

BBRC

Solve for E_1 , using an iterative procedure.

$$* \quad \Delta E_1 = \frac{M_1 - E_{1\ old} + e_1 \sin E_{1\ old}}{1 - e_1 \cos E_1}$$

$$* \quad E_{1\ new} = E_{1\ old} + \Delta E_1$$

*As an initial value, take $E_{1\ old} = M_1$. Continue the iteration until $|\Delta E_1| < 1 \times 10^{-6}$.

$$* \quad P_1 = a_1(1 - e_1 \cos E_1)$$

$$* \quad \xi_1 = a_1(\cos E_1 - e_1)$$

$$* \quad \eta_1 = b_1 \sin E_1$$

$$* \quad n_1 = \sqrt{\frac{398605}{a_1^3}}$$

$$* \quad \dot{\xi}_1 = \frac{-n_1 a_1^2}{P_1} \sin E_1$$

$$* \quad \dot{\eta}_1 = \frac{n_1 a_1 b_1}{P_1} \cos E_1$$

$$* \left\{ \begin{aligned} x_1 &= \ell_{11}\xi_1 + \ell_{21}\eta_1 \\ y_1 &= m_{11}\xi_1 + \ell_{21}\eta_1 \\ z_1 &= n_{11}\xi_1 + n_{21}\eta_1 \end{aligned} \right.$$

$$* \left\{ \begin{aligned} \dot{x}_1 &= \ell_{11}\dot{\xi}_1 + \ell_{21}\dot{\eta}_1 \\ \dot{y}_1 &= m_{11}\dot{\xi}_1 + m_{21}\dot{\eta}_1 \\ \dot{z}_1 &= n_{11}\dot{\xi}_1 + n_{21}\dot{\eta}_1 \end{aligned} \right.$$

This defines the vectors which are constant during the entire calculation.

$$\vec{P}_1 = x_1\hat{i} + y_1\hat{j} + z_1\hat{k}$$

$$\dot{\vec{P}}_1 = \dot{x}_1\hat{i} + \dot{y}_1\hat{j} + \dot{z}_1\hat{k}$$

Some of the relationships need to be calculated only once for the entire orbit. These are as follows

$$* \left\{ \begin{array}{ll} \cos \omega_2 & \cos i_2 \\ \sin \omega_2 & \sin i_2 \\ b_2 = a_2(1 - e_2^2)^{\frac{1}{2}} & \\ n_2 = \sqrt{\dfrac{398605}{a_2^3}} & \end{array} \right.$$

For each point defined by a $(\Omega_2\ ,\ V_2)$, the following calculations are performed.

* Considered $r_1 = (\overline{SS})(a_1)$
* $r = (\overline{SL})(a_2)$
* Subdivide the interval r_1 to r_7 into six equal parts to generate $r_1\ ,\ r_2\ ,\ r_3\ ,\ ---\ ,\ r_7$.

Point A: Take a value of Ω_2 and V_2 .

$$* \quad E_2 = 2 \tan^{-1}\left\{ \sqrt{\frac{1 - e_2}{1 + e_2}} \tan \frac{V_2}{2} \right\}$$

$\frac{E_2}{2}$ may be in the first or second quadrant only.

$$* \quad P_2 = a_2(1 - e_2 \cos E_2)$$

$$* \quad \xi_2 = a_2(\cos E_2 - e_2)$$

$$* \quad \eta_2 = b_2 \sin E_2$$

$$* \quad \begin{cases} \ell_{12} = \cos \Omega_2 \cos \omega_2 - \sin \Omega_2 \sin \omega_2 \cos i_2 \\ \ell_{22} = -\cos \Omega_2 \sin \omega_2 - \sin \Omega_2 \cos \omega_2 \cos i_2 \end{cases}$$

$$* \quad z_2 = n_{12}\, \xi_2 + n_{22}\, \eta_2$$

Now, test to see if OSO is north of the CSM. This test should be used until the first time it is passed for a particular value of Ω_2 . This is then reinstated for the next value of Ω_2 , etc.

*Test:

If z_1 is positive, return to Point A, and a new value of V_2 if $z_2 \leq z_1$.

If z_1 is negative, return to Point A, and a new value of V_2 if $z_1 \geq z_2$.

If the test is passed, continue below.

$$* \quad \begin{cases} m_{12} = \sin \Omega_2 \cos \omega_2 + \cos \Omega_2 \sin \omega_2 \cos i_2 \\ n_{12} = \sin \omega_2 \sin i_2 \end{cases}$$

$$* \quad \begin{cases} m_{22} = -\sin \Omega_2 \sin \omega_2 + \cos \Omega_2 \cos \omega_2 \cos i_2 \\ n_{22} = \cos \omega_2 \sin i_2 \end{cases}$$

$$* \quad \begin{cases} y_2 = m_{12}\xi_2 + m_{22}\eta_2 \\ x_2 = \ell_{12}\xi_2 + \ell_{22}\eta_2 \end{cases}$$

This defines the vector

$$\vec{P}_2 = x_2\hat{i} + y_2\hat{j} + z_2\hat{k}$$

The rotation to plane of the transfer orbit is calculated as follows. (See Fig. B-2.)

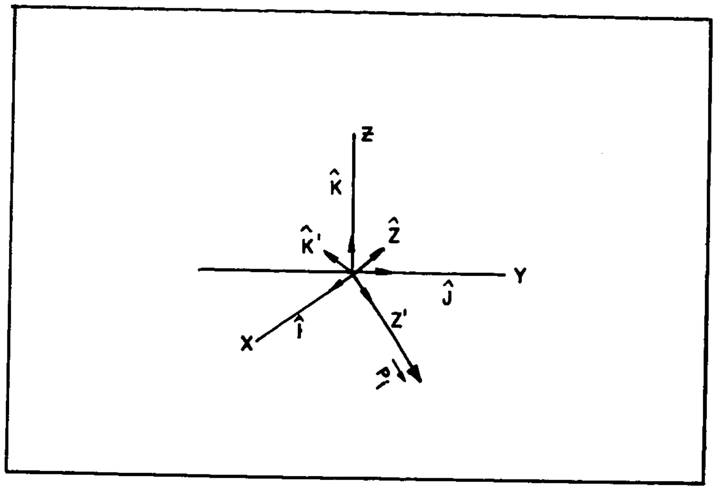


Fig. B-2 Rotation Vector Notation

$$\hat{i}' = \frac{\vec{P}_1}{P_1}$$

* $$a_{11} = \frac{x_1}{P_1}$$

* $$a_{12} = \frac{y_1}{P_1}$$

* $$a_{13} = \frac{z_1}{P_1}$$

$$\hat{k}' = \frac{\vec{P}_1 \times \vec{P}_2}{|\vec{P}_1 \times \vec{P}_2|} = \frac{1}{|\vec{P}_1 \times \vec{P}_2|} \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \end{vmatrix}$$

$$= \frac{1}{|\vec{P}_1 \times \vec{P}_2|} \left\{ \hat{i}(y_1 z_2 - y_2 z_1) - \hat{j}\,(x_1 z_2 - z_1 x_2) + \hat{k}\,(x_1 y_2 - x_2 y_1) \right\}$$

* $$|\vec{P}_1 \times \vec{P}_2| = \sqrt{(y_1 z_2 - y_2 z_1)^2 + (z_1 x_2 - x_1 z_2)^2 + (z_1 y_2 - z_2 y_1)^2}$$

* $$a_{31} = \frac{1}{|\vec{P}_1 \times \vec{P}_2|} \left\{ y_1 z_2 - y_2 z_1 \right\}$$

* $$a_{32} = \frac{1}{|\vec{P}_1 \times \vec{P}_2|} \left\{ z_1 x_2 - x_1 z_2 \right\}$$

$$* \quad a_{33} = \frac{1}{|\vec{P}_1 \times \vec{P}_2|} \left\{ x_1 y_2 - x_2 y_1 \right\}$$

$$\hat{j}' = \hat{k}' \times \hat{i}' = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_{31} & a_{32} & a_{33} \\ a_{11} & a_{12} & a_{13} \end{vmatrix}$$

$$= \hat{i}(a_{32}a_{13} - a_{12}a_{33}) - \hat{j}\,(a_{31}a_{13} - a_{33}a_{11}) + \hat{k}\,(a_{31}a_{12} - a_{11}a_{32})$$

$$* \quad a_{21} = a_{32}a_{13} - a_{12}a_{33}$$

$$* \quad a_{22} = -a_{31}a_{13} + a_{33}a_{11}$$

$$* \quad a_{23} = a_{31}a_{12} - a_{11}a_{32}$$

$$\hat{i}' = a_{11}\hat{i} + a_{12}\hat{j} + a_{13}\hat{k}$$

$$\hat{j}' = a_{11}\hat{i} + a_{22}\hat{j} + a_{23}\hat{k}$$

$$\hat{k}' = a_{31}\hat{i} + a_{32}\hat{j} + a_{33}\hat{k}$$

$$\begin{bmatrix} \hat{i}' \\ \hat{j}' \\ \hat{k}' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{21} & a_{31} \\ a_{12} & a_{22} & a_{32} \\ a_{13} & a_{23} & a_{33} \end{bmatrix} \begin{bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{bmatrix}$$

Inverting yields

$$\begin{bmatrix} \hat{i} \\ \hat{j} \\ \hat{k} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{21} & a_{31} \\ a_{12} & a_{22} & a_{32} \\ a_{13} & a_{23} & a_{33} \end{bmatrix} \begin{bmatrix} i' \\ j' \\ k' \end{bmatrix} \quad \text{or} \quad \begin{aligned} \hat{i} &= a_{11}\hat{i}' + a_{21}\hat{j}' + a_{31}\hat{k}' \\ \hat{j} &= a_{12}\hat{i}' + a_{22}\hat{j}' + a_{32}\hat{k}' \\ \hat{k} &= a_{13}\hat{i}' + a_{23}\hat{j}' + a_{33}\hat{k}' \end{aligned}$$

In the new coordinate system

$$\vec{P}_1 = x_1 \, \hat{i}'$$

$$* \quad X_1 = P_1$$

$$\vec{P}_2 = x_2\hat{i} + y_2\hat{j} + z_2\hat{k}$$

$$= x_2(a_{11}\hat{i}' + a_{21}\hat{j}' + a_{31}\hat{k}')$$

$$+ y_2(a_{12}\hat{i}' + a_{22}\hat{j}' + a_{32}\hat{k}')$$

$$+ z_2(a_{13}\hat{i}' + a_{23}\hat{j}' + a_{33}\hat{k}')$$

$$= \hat{i}' \; (x_2a_{11} + y_2a_{12} + z_2a_{13})$$

$$+ \hat{j}' \; (x_2a_{21} + y_2a_{22} + z_2a_{23})$$

$$+ \hat{k}' \; (x_2a_{31} + y_2a_{32} + z_2a_{33})$$

Since this is in the plane of the unit vectors $\hat{i}'$ and $\hat{j}'$, then

$$x_2a_{31} + y_2a_{32} + z_2a_{33} = 0$$

* $$X_2 = x_2a_{11} + y_2a_{12} + z_2a_{13}$$

* $$Y_2 = x_2a_{21} + y_2a_{22} + z_2a_{23}$$

* $$\cos \Delta\phi = \frac{\vec{P}_1 \cdot \vec{P}_2}{(P_1)(P_2)} = \frac{X_2}{P_2}$$

* $$\sin \Delta\phi = \frac{\vec{P}_1 \times \vec{P}_2 \cdot \hat{k}}{(P_1)(P_2)} = \frac{1}{(P_1)(P_2)} \begin{vmatrix} X_1 & 0 & 0 \\ X_2 & Y_2 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

$$= \frac{Y_2}{P_2}$$

* $$\Delta\phi = \tan^{-1} \left(\frac{\sin \Delta\phi}{\cos \Delta\phi}\right)$$

* Test for the correct quadrant.

If $\Delta\phi < 40°$, take the next V_2 , and go to point A.

If $40° \leq \Delta\phi \leq 230°$, continue with the calculations below.

If $\Delta\phi \geq 230°$, take a new value of Ω_2 , and go to point A with the V_2 .

Point B

$$* \begin{cases} \dot{\xi}_2 = \dfrac{-n_2 a_2^2}{P_2} \sin E_2 \\ \\ \dot{\eta}_2 = \dfrac{n_2 a_2 b_2}{P_2} \cos E_2 \end{cases}$$

$$* \begin{cases} \dot{x}_2 = \ell_{12} \dot{\xi}_2 + \ell_{22} \dot{\eta}_2 \\ \dot{y}_2 = m_{12} \dot{\xi}_2 + m_{22} \dot{\eta}_2 \\ \dot{z}_2 = n_{12} \dot{\xi}_2 + n_{22} \dot{\eta}_2 \end{cases}$$

This defines the vector

$$\dot{\vec{P}}_2 = \dot{x}_2 \hat{i} + \dot{y}_a \hat{j} + \dot{z}_2 \hat{k}$$

The coordinates in-plane are the following. (See Fig. B-3.)

$$\vec{u} = (X_2 - X_1)\hat{i}' + y_2 \hat{j}'$$

$$\cos \gamma = \frac{\hat{j}' \cdot \vec{u}}{|\vec{u}|}$$

$$* \qquad u = \sqrt{(X_2 - X_1)^2 + Y_2^2}$$

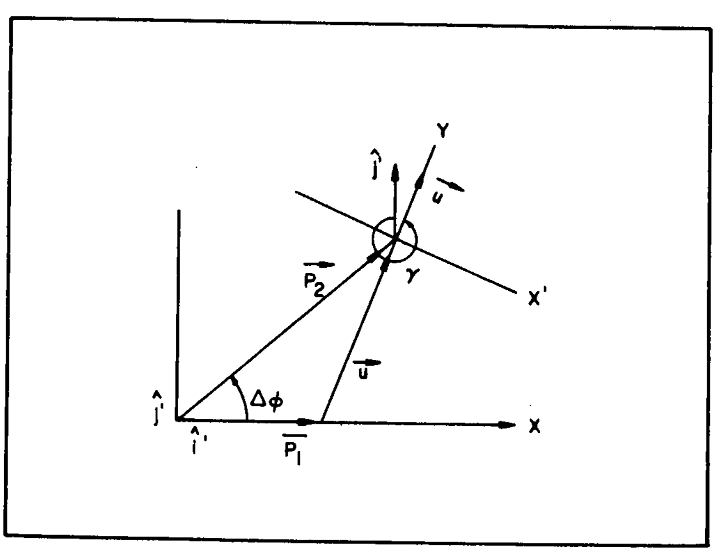


Fig. B-3 In-Plane Coordinates

$$* \quad \cos\gamma = \frac{Y_2}{|u|}$$

$$\sin\gamma = \frac{\hat{j}' \times \vec{u} \cdot \hat{k}'}{u} = \frac{1}{|\vec{u}|} \begin{vmatrix} 0 & 1 & 0 \\ (X_2-X_1) & Y_2 & 0 \\ 0 & 0 & 1 \end{vmatrix}$$

$$* \quad = \frac{(X_1-X_2)}{u}$$

Translate the axes to P_2 and rotate.

$$\begin{bmatrix} X' \\ Y' \end{bmatrix} \begin{bmatrix} \cos\gamma & \sin\gamma \\ -\sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} - \begin{bmatrix} X_2 \\ Y_2 \end{bmatrix}$$

$$* \quad Y_1' = -u$$

Let $a_R = r_j$, $j = 1$, --- , 7

The ellipse exists if

$$* \quad 4a_R \geq P_1 + P_2 + u$$

Make this test. If an a_R fails this test, go on to the next value. If the a_R passes the test, continue below.

$$* \quad X_\nu' = \frac{\pm\sqrt{4(Y_1')^2\ (2a_R-P_2)^2 - \left[(2a_R-P_2)^2 - (2a_R-P_1)^2 + (Y_1')^2\right]^2}}{2Y_1'}$$

$$* \quad Y_\nu' = \frac{(2a_R-P_2)^2 - (2a_R-P_1)^2 + (Y_1')^2}{2Y_1'}$$

Each value of a_R gives two values of X_ν' which must be considered. For each value of X_ν' , continue as below.

$$\begin{bmatrix} X_\nu \\ Y_\nu \end{bmatrix} = \begin{bmatrix} \cos\gamma & -\sin\gamma \\ \sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} X' \\ Y' \end{bmatrix} + \begin{bmatrix} X_2 \\ Y_2 \end{bmatrix}$$

$$* \quad X_\nu = X_\nu' \cos\gamma - Y_\nu' \sin\gamma + X_2$$

$$* \quad Y_\nu = X_\nu' \sin\gamma + Y_\nu' \cos\gamma + Y_2$$

The distance to the empty focus is

$$* \quad d = \sqrt{X_\nu^2 + Y_\nu^2}$$

$$* \quad b_R = \sqrt{a_R^2 - \frac{d^2}{4}}$$

$$* \quad e_R = \frac{\sqrt{a_R^2 - b_R^2}}{a_R} = \frac{d}{2a_R}$$

NOTE: There will be a different value of d, b_R and e_R for each value of X_ν'.

The direction of pericenter is

$$\hat{w} = -\frac{1}{d}\left\{X_\nu \hat{i}' + Y_\nu \hat{j}'\right\}$$

$$= w_x \hat{i}' + w_y \hat{j}'$$

$$* \quad w_x = -\frac{X\nu}{d}$$

$$* \quad w_y = -\frac{Y\nu}{d}$$

The true anomaly of $\vec{P}_1$ in this plane is computed as follows

$$\cos V_{R_1} = \frac{\hat{w} \cdot \hat{P}_1}{\vec{P}_1}$$

$$* \quad = \frac{w_x X_1 + w_y Y_1}{P_1} = w_x$$

$$\sin V_{R_1} = \frac{w \times \vec{P}_1 \cdot \hat{K}'}{P_1} = \frac{1}{P_1}\begin{bmatrix} w_X & w_Y & 0 \\ X_1 & Y_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$* \quad = \frac{w_X Y_1 - w_Y X_1}{P_1} = - w_Y$$

Check the quadrants when forming.

$$* \quad V_{R_1} = \tan^{-1}\left(\frac{\sin V_{R_1}}{\cos V_{R_1}}\right)$$

* The true anomaly of $\vec{P}_2$ is $V_{R_2} = V_{R_1} + \Delta\phi$

$$* \quad E_{Ri} = 2 \tan^{-1} \left\{ \frac{\sqrt{1 - e_R}}{\sqrt{1 + e_R}} \tan \frac{V_{Ri}}{2} \right\}$$

E_{Ri} is only in the first and second quadrant.

$$* \quad Ti = \sqrt{\frac{a_R^{\ 3}}{398605.}} \left(E_{Ri} - \ell_R \sin E_{Ri}\right)$$

$$* \quad n_R = \sqrt{\frac{398605.}{a_R^{\ 3}}}$$

$$* \quad \text{If } V_{R1} \leq V_{R2}, \; T = T_2 - T_1$$

$$\text{If } V_{R1} > V_{R2}, \; T = \frac{2\pi}{nR} - (T_1 - T_2)$$

The orientation of plane of trajectory is

$$* \quad i_R = \cos^{-1} (a_{33}) \text{ (only in first quadrant)}$$

$$* \sin \Omega_R = \frac{a_{31}}{\sin i_R}$$

$$* \cos \Omega_R = \frac{-a_{32}}{\sin i_R}$$

The calculation of ω_R is

$$* \sin (\omega_R + V_{R1}) = \frac{z_1}{P_1 \sin i_R}$$

$$* \cos (\omega_R + V_{R1}) = \frac{1}{P_1} (x_1 \cos \Omega_R + y_1 \sin \Omega_R)$$

$$* \omega_R = \tan^{-1} \left[\frac{\sin (\omega_R + V_{R1})}{\cos (\omega_R + V_{R1})}\right] - V_{R1}$$

Check for the proper quadrant.

$$0° \leq R \leq 360°$$

To calculate the velocity, use a_R, e_R, i_R, ω_R, Ω_R and E_R, and E_{RS} to find two velocity vectors $\vec{P}_{1R}$ at the beginning of the flight and $\vec{P}_{2R}$ at the end of the flight. The calculations are as follows

$$* \begin{cases} \ell_{1R} = \cos \Omega_R \cos \omega_R - \sin \Omega_R \sin \omega_R \cos i_R \\ m_{1R} = \sin \Omega_R \cos \omega_R + \cos \Omega_R \sin \omega_R \cos i_R \\ n_{1R} = \sin \omega_R \sin i_R \end{cases}$$

$$* \begin{cases} \ell_{1R} = \cos \Omega_R \sin \omega_R - \sin \Omega_R \cos \omega_R \cos i_R \\ m_{2R} = \sin \Omega_R \sin \omega_R + \cos \Omega_R \cos \omega_R \cos i_R \\ n_{2R} = \cos \omega_R \sin i_R \end{cases}$$

$$\left.\begin{array}{l} * \quad \dot{\xi}_{iR} = \dfrac{-n_R a_R^2}{P_i} \sin E_{R1} \\ * \quad \dot{\eta}_{iR} = \dfrac{n_R a_R b_R}{P_i} \cos E_{R1} \\ * \begin{cases} \dot{x}_{iR} = \ell_{1R} \ \dot{\xi}_{iR} + \ell_{2R} \ \dot{\eta}_{iR} \\ \dot{y}_{iR} = m_{1R} \ \dot{\xi}_{iR} + m_{2R} \ \dot{\eta}_{iR} \\ \dot{z}_{iR} = n_{1R} \ \dot{\xi}_{iR} + n_{2R} \ \dot{\eta}_{iR} \end{cases} \end{array}\right\} \quad i = 1, 2$$

$$* \quad \Delta V = \left\{ \sqrt{(\dot{x}_1 - \dot{x}_{1R})^2 + (\dot{y}_1 - \dot{y}_{1R})^2 + (z_1 - z_{1R})^2} + \sqrt{(\dot{x}_2 - \dot{x}_{2R})^2 + (\dot{y}_2 - \dot{y}_{2R})^2 + (\dot{z}_2 - \dot{z}_{2R})^2} \right\} *3280.8$$

Compare ΔV and V. If $\Delta V > V$, do not print out the line, but go on to the next V_2. If <V>V, continue with the caluculation.

The calculation of phase angle is

$$* \quad M_{22} = E_2 - e_2 \sin E_2$$

$$* \quad M_3 = T \, n_2$$

$$* \quad M_{21} = M_{22} - M_3$$

If necessary, add 360 degrees to make M_{21} a positive angle.

$$M_{21} = E_3 - e_2 \sin E_3$$

*Solve this by iteration.

$$\Delta E_3 = \frac{M_{21} - E_{3\ old} + e_2 \sin E_{3\ old}}{1 - e_2 \cos E_{3\ old}}$$

$$E_3 = E_{3\ old} + \Delta E_3$$

As an initial value, take $E_{3\ old} = M_{21}$. Continue the iteration until $|\Delta E_3| < 1 \times 10^{-6}$.

$$* \ V_0 = 2 \tan^{-1} \left\{ \sqrt{\frac{1 + e_2}{1 - e_2}} \tan \frac{E_3}{2} \right\}$$

$$* \ \Delta\psi = V_2 - V_0$$

If necessary, add 360 degrees to guarantee that $\Delta\psi$ is positive.

Print Out
(E14.8 Format)

CSM elements	$a_1, e_1, i_1, \Omega_1, w_1, M_1, P_1$
OSO elements	a_2, e_2, i_2, w_2

Each new Ω_2

Each new $\Delta\phi$ and V_2

Each ΔV, T, $\Delta\psi$, a_R, P_2

This program is illustrated in flow chart format and is presented in Fig. B-4.

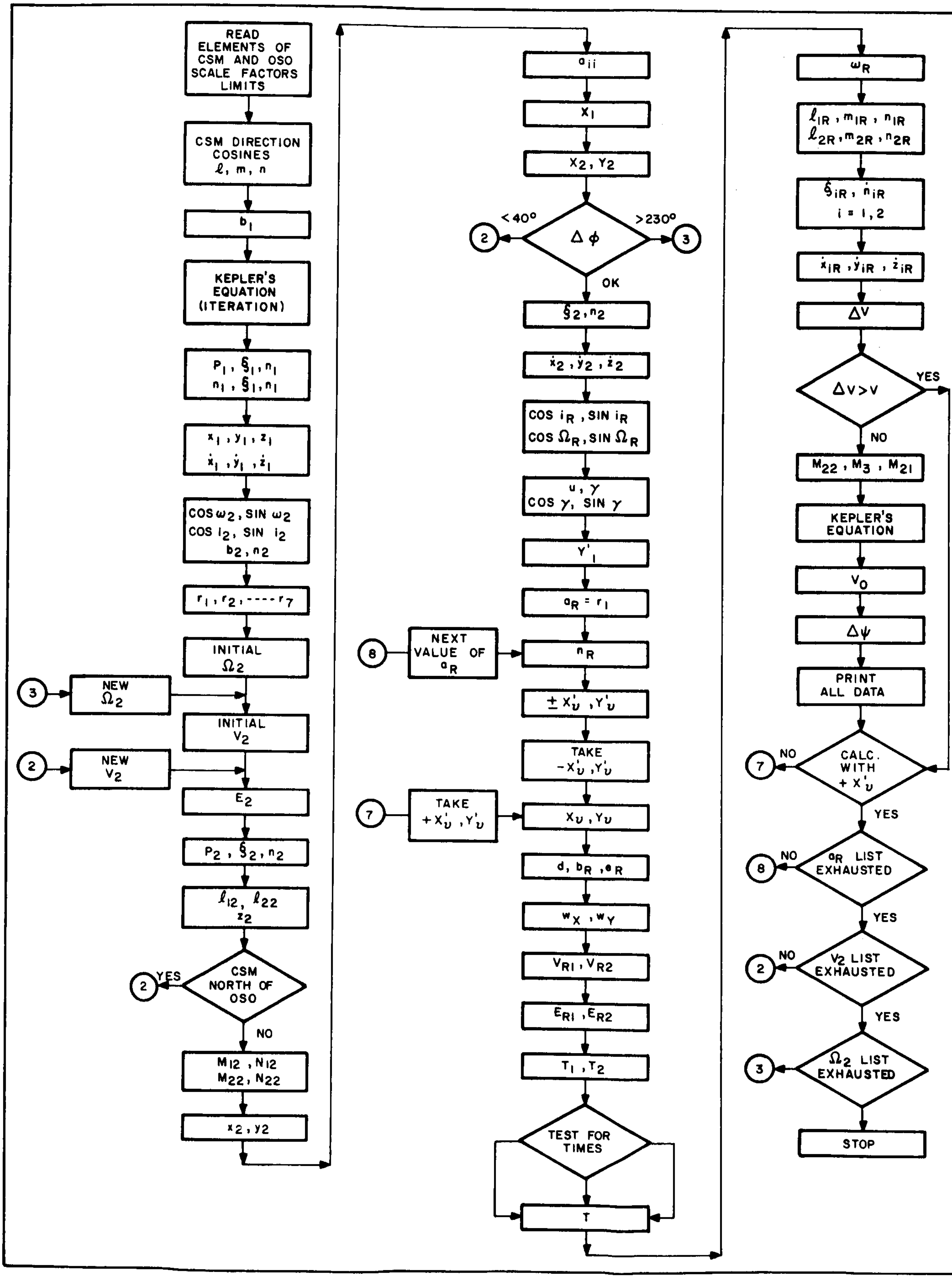


Fig. B-4 Flow Chart - Rendezvous

BBRC

Appendix C
COLINEAR CAPTURE DYNAMICS

The forces and motions of the CSM and the OSO are determined for the condition of a colinear collision of the two vehicles. In general, the procedure for capturing OSO consists of aligning the two vehicles in orbit; establishing a closing velocity which permits contact of the capture mechanism and the OSO; compressing a spring in the capture mechanism to absorb kinetic energy and permit the two vehicles to continue at the same average velocities; and despinning the OSO. The equations are developed herein for the colinear capture phase forces.

The equations are developed below for the CSM and OSO with a compression spring in series with the two masses during the velocity equalization phase. Since this phase of capture occurs over a short time span, we can neglect orbital effects and concentrate on the relative motions of the two vehicles. The equations are established for an initial velocity of the CSM. The coordinate system is shown in Fig. C-1.

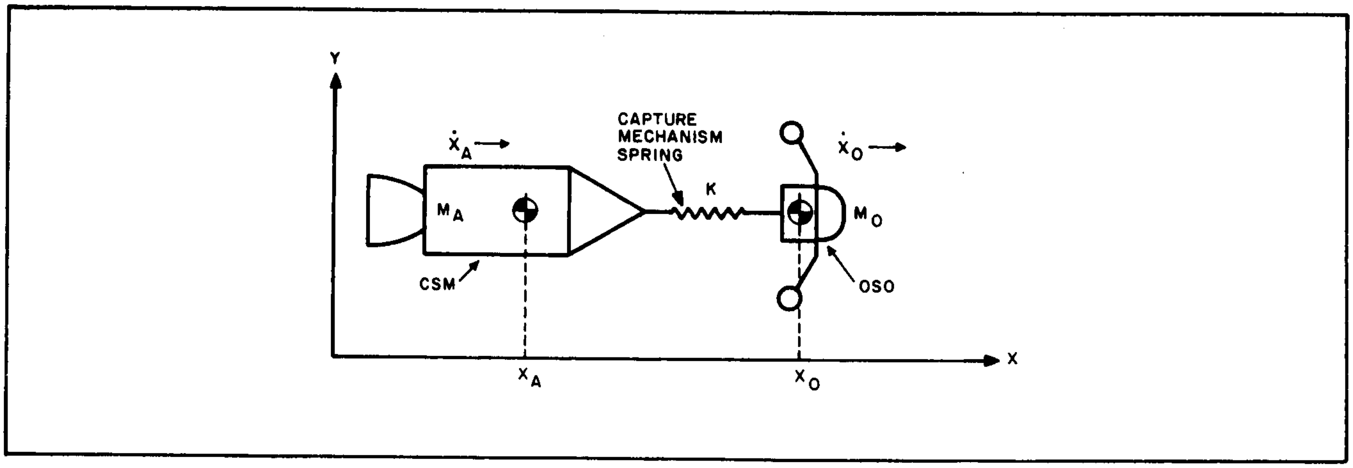


Fig. C-1 CSM/OSO Coordinate System

The conservation of linear momentum implies that the linear momentum of the system before impact is equal to the linear momentum of the mass center after impact.

$$P_o = M_A \dot{X}_A + M_O \dot{X}_O \tag{C.1}$$

Before impact,

$$\dot{X}_O = 0$$

$$P_o = M_A \dot{X}_{A_O} \tag{C.2}$$

Writing the force balance equations for CSM and OSO during impact

$$M_A \ddot{X}_A = -K \left[(X_A - X_{A_0}) - (X_O - X_{O_0}) \right] \tag{C.3}$$

$$M_O \ddot{X}_O = -K \left[(X_O - X_{O_0}) - (X_A - X_{A_0}) \right] \tag{C.4}$$

The location of the mass center R can be written

$$R = \frac{M_A X_A + M_O X_O}{M_A + M_O} \tag{C.5}$$

and

$$\dot{R} = \frac{M_A \dot{X}_A + M_O \dot{X}_O}{M_A + M_O} \tag{C.6}$$

From Eq. (C.1)

$$\dot{R} = \frac{P_O}{M_A + M_O} = \text{constant} = \frac{M_A \dot{X}_{A_0}}{M_A + M_O} \tag{C.7}$$

Rewriting Eq. (C.1) to determine the velocity of OSO yields

$$\dot{X}_O = \frac{P_O}{M_O} - \frac{M_A \dot{X}_A}{M_O} \tag{C.8}$$

The above expression can be integrated to determine the displacement for the boundary conditions

$$X_O = X_{O_0}$$

and

$$\dot{X}_O = 0$$

at

$$t = 0$$

After performing the above operations

$$X_0 = \frac{P_0 t}{M_0} - \frac{M_A}{M_0} (X_A - X_{A_0}) + X_{0_0} \qquad (C.9)$$

Substituting the OSO displacement Eq. (C.9) into the CSM force, balance Eq. (C.3) and rearrange

$$\ddot{X}_A + K\left(\frac{M_A + M_0}{M_A M_0}\right)X_A = KX_{A_0}\left(\frac{M_A + M_0}{M_A M_0}\right) + \frac{KP_0 t}{M_A M_0} \qquad (C.10)$$

Rewriting Eq. (C.10) for convenience

$$\ddot{X}_A + AX_A = B + Ct \qquad (C.11)$$

where

$$A = K\left(\frac{M_A + M_0}{M_A M_0}\right) \qquad (C.12)$$

$$B = KX_{A_0}\left(\frac{M_A + M_0}{M_A M_0}\right) \qquad (C.13)$$

$$C = \frac{KP_0}{M_A M_0} \qquad (C.14)$$

The solution of Eq. (C.11) is determined for the boundary conditions

$$X_A = X_{A_0}$$

and

$$\dot{X}_A = \dot{X}_{A_0}$$

at

$$t = 0$$

The expression for the displacement of the CSM then becomes

$$X_A = (X_{A_0} - \frac{B}{A}) \cos \sqrt{At} + \left(\frac{\dot{X}_{A_0}}{\sqrt{A}} - \frac{C}{A\sqrt{A}} \right) \sin \sqrt{At} + \frac{B}{A} + \frac{Ct}{A} \qquad (C.15)$$

Differentiating the displacement Eq. (C.15) gives

$$\dot{X}_A = - (X_{A_0} - \frac{B}{A}) \sqrt{A} \sin \sqrt{A}\, t + (\dot{X}_{A_0} - \frac{C}{A}) \cos \sqrt{A}\, t + \frac{C}{A} \qquad (C.16)$$

The displacements, velocities, and accelerations of the two masses are now determined.

The function of the spring in the attachment mechanism is two-fold. One is to reduce the impact load, and the second is to remove kinetic energy from the system and store it as potential energy in the spring. This is accomplished by locking the spring in its fully compressed state. In general, for a collision of this type, the two bodies will attain some equal average velocity after impact so that they will be coupled together without producing large oscillating coupling forces; thus a reduction in kinetic energy is obtained. Locking the spring at the instant it is fully compressed, which is equivalent to the time at which the two vehicles attain the same velocity, permits the vehicles to be coupled together and exhibit the same average velocities. There will be an oscillation of the mass centers about the average velocity at a frequency determined by the spring constant of the coupled structure and their combined masses. The magnitude of the oscillating coupling force is equal to the force required to fully compress the attachment mechanism spring.

The time required to compress the spring and attain velocity equalization of the two vehicles is determined next.

Equating the CSM and OSO velocity Eqs. (C.16) and (C.3) and solving for the time, yields

$$t = \frac{\pi}{2\sqrt{A}} = t_1 \qquad (C.17)$$

The energy stored in the capture mechanism spring at time t_1 is

$$E = \frac{1}{2} KS^2 \qquad (C.18)$$

where S is the distance through which the spring is compressed. The magnitude of S can be found from the right side of Eqs. (C.3) and (C.4) divided by the spring constant K.

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The displacement of the spring is

$$S = \left[(\dot{X}_{A_0} - \frac{C}{A}) \frac{1}{\sqrt{A}} \sin \sqrt{A}\; t \right] \left[1 + \frac{M_A}{M_0} \right] \qquad (C.19)$$

For an actual structure, there will be one spring constant for the structure and one for the capture mechanism spring forming a series spring combination. For this arrangement, the spring constant used in the preceding equations is replaced by an effective spring constant for the system. The expression for K is

$$K = \frac{K_1 K_2}{K_1 + K_2} \qquad (C.20)$$

where

K_1 = spring constant of structure

K_2 = spring constant of capture mechanism spring

The equations developed herein are valid from $t = 0$ to $t = t_1$, where t_1 is the time the capture mechanism spring is locked in its maximum compressed state. A new set of equations is then required to determine the response of the system from time t_1 on. After t_1, the coupled structures will oscillate about the system center of mass in opposed motion with the frequency determined by the spring constant of the structure and their masses. The oscillating force will have a maximum value equal to the magnitude of the coupling force at the time t_1.

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Appendix D
ECCENTRIC CAPTURE DYNAMICS

The equations for colinear capture of OSO have been presented in Appendix C. This appendix presents the development of the equations for an eccentric impact during OSO capture. An eccentric impact is possible because of the uncertainties of the CSM aiming accuracy. The CSM RCS permits control of the CSM attitude to a reasonable degree of accuracy. However, a dead band, about which the attitude can vary 0.5 degrees, is present. This dead band oscillation results in an eccentricity of ±2.7 inches at the end of a ten foot boom attached to the front of the Command Module. Thus, for perfect alignment of CSM and OSO, an error of ±2.7 inches can be present. This eccentric distance produces a moment on the OSO in addition to the colinear impact force. Since the OSO is spin stabilized in orbit, a moment applied to the body results in gyroscopic rotations to change the spin axis. A nutation and precession of the spin axis will occur as long as the impact force is acting at the eccentric distance.

An estimate of the gyroscopic disturbance produced by the moment is required to conceive the capture mechanism attachment head and to give an indication of the magnitude of the rates produced.

As in Appendix C, the orbital effects will be neglected because of the short time duration considered. The moment produced by the eccentric distance and the impact force will be considered equal in magnitude to the eccentric distance multiplied by the impact force determined from the colinear capture equations. The displacement of the eccentric capture force will be small in relation to the total spring displacement producing the force; therefore, this small displacement will be neglected. Furthermore, small angle approximations will be made to expedite the solution.

The coordinate system used for this analysis is shown in Fig. D-1. The coordinate transformation from the fixed axes X, Y, Z, to the body axes is accomplished by a rotation through an angle ψ about the Z axis and a rotation through an angle θ about the Y' axis.

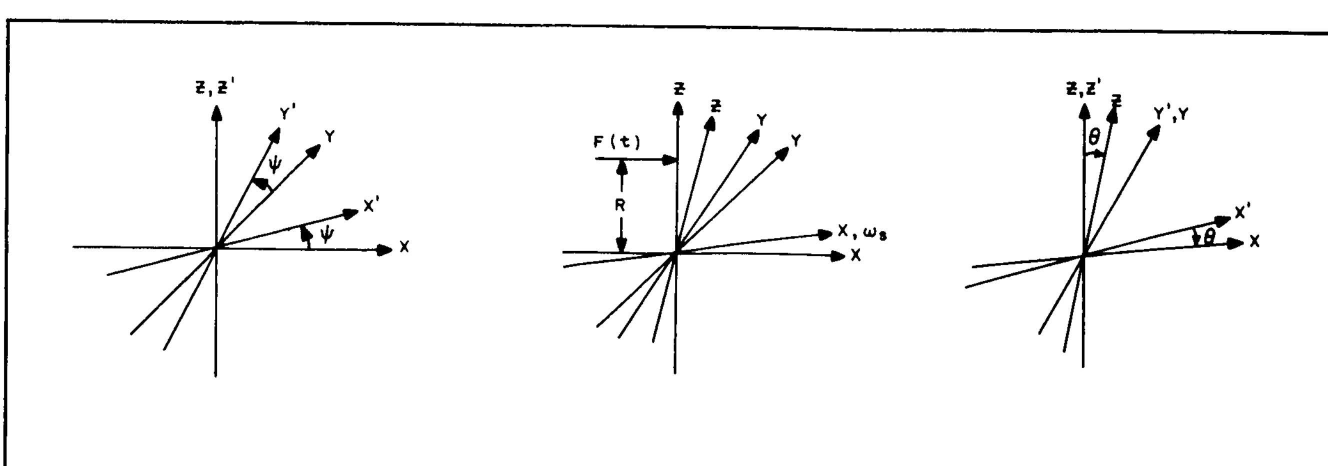

Fig. D-1 Euler Angle Transformations

The rotation through ψ about Z is

$$X = X' \cos \psi - Y' \sin \psi$$
$$Y = X' \sin \psi + Y' \cos \psi$$
$$Z = Z'$$

The rotation through θ about Y' is

$$X' = X \cos \theta + Z \sin \theta$$
$$Y' = Y$$
$$Z' = -X \sin \theta + Z \cos \theta$$

$$X = X \cos \psi \cos \theta - Y \sin \psi + Z \sin \theta \cos \psi$$
$$Y = X \cos \theta \sin \psi + Y \cos \psi + Z \sin \psi \sin \theta$$
$$Z = -X \sin \theta + Z \cos \theta$$

For the small angle approximation

$$X = X - Y\psi + Z\theta \qquad (D.1)$$
$$Y = X\psi + Y + Z\theta \qquad (D.2)$$
$$Z = -X\theta + Z \qquad (D.3)$$

The equations are developed for the spin axis of the OSO aligned with the +X body axis. The impact capture force is assumed to act in the +X direction at an eccentric distance +Z.

The equations for the gyroscopic response are

$$M_X = I_{XX}\dot{\omega}_X + (I_{ZZ} - I_{YY})\ \omega_Y\omega_Z \qquad (D.4)$$
$$M_Y = I_{YY}\ \dot{\omega}_Y + (I_{XX} - I_{ZZ})\ \omega_X\omega_Z \qquad (D.5)$$
$$M_Z = I_{ZZ}\dot{\omega}_Z + (I_{YY} - I_{XX})\omega_X\omega_Y \qquad (D.6)$$

Let

$$I_{XX} = I_S,\ I_{YY} = I_{ZZ} = I_T \qquad (D.7)$$

$$\omega_X = \dot{\phi} = \omega_S,\ \omega_Y = \dot{\theta},\ \omega_Z = \dot{\psi} \qquad (D.8)$$

The moments are

$$M_X = 0 \qquad (D.9)$$

$$M_Y = RF(t) \qquad (D.10)$$

$$M_Z = 0 \qquad (D.11)$$

Equation (D.4) reduces to zero. Substitution of the moments into Eqs. (D.5) and (D.6) yields

$$\ddot{\psi} = \left(\frac{I_S - I_T}{I_T}\right)\omega_S\,\dot{\theta} \tag{D.12}$$

$$\ddot{\theta} = -\left(\frac{I_S - I_T}{I_T}\right)\omega_S\dot{\psi} + \frac{M_Y}{I_T} \tag{D.13}$$

Equation (D.12) can be integrated to give ψ, for the boundary conditions $\theta = 0$, $\dot{\psi} = 0$ for $t = 0$. Thus

$$\dot{\psi} = \left(\frac{I_S - I_T}{I_T}\right)\omega_S\theta \tag{D.14}$$

Substitution of Eq. (D.14) into Eq. (D.13) gives

$$\ddot{\theta} + \left[\left(\frac{I_S - I_T}{I_T}\right)\omega_S\right]\theta^2 = \frac{RF(t)}{I_T} \tag{D.15}$$

where F(t) is the impact force from the colinear capture problem. From Eq. (C.19), Appendix C, F(t) is

$$F(t) = KS(t) \tag{D.16}$$

$$F(t) = K\left[\left(\dot{X}_{A_0} - \frac{C}{A}\right)\frac{1}{\sqrt{A}}\sin\sqrt{A}\,t\right]\left[1 + \frac{M_A}{M_0}\right] \tag{D.17}$$

For convenience, let

$$\alpha = \left(\frac{I_S - I_T}{I_T}\right)\omega_S \tag{D.18}$$

$$\gamma = \frac{1}{\sqrt{A}}\left(\dot{X}_{A_0} - \frac{C}{A}\right) \tag{D.19}$$

then

$$\ddot{\theta} + \alpha^2\theta = \frac{R\gamma D}{I_T}\left(1 + \frac{M_A}{M_0}\right)\sin\sqrt{A}\,t \tag{D.20}$$

The solution to Eq. (D.20) is

$$\theta = \left[\frac{-\sqrt{A}}{\alpha}\sin\alpha t + \sin\sqrt{A}\,t\right]\frac{RK\gamma}{I_T}\left(\frac{1 + \frac{M_A}{M_0}}{-A + \alpha^2}\right) \tag{D.21}$$

$$\dot{\theta} = \left[-\cos\alpha t + \cos\sqrt{A}\,t\right]\frac{\sqrt{A}\,RK\gamma}{I_T}\left(\frac{1 + \frac{M_A}{M_0}}{-A + \alpha^2}\right) \tag{D.22}$$

From Eqs. (D.14) and (D.21)

$$\dot{\psi} = \left[-\sqrt{A} \sin \alpha t + \alpha \sin \sqrt{A}\, t \right] \frac{RK_Y}{I_T} \left(\frac{1 + \frac{M_A}{M_O}}{-A + \alpha^2} \right) \tag{D.23}$$

Equation (D.23) can be integrated directly to give the angle ψ. The boundary condition is

$$\psi \rightarrow 0 \text{ at } t = 0$$

$$\psi = \left[\frac{\alpha}{\sqrt{A}} (1 - \cos \sqrt{A}\, t) - \frac{\sqrt{A}}{\alpha} (1 - \cos \alpha t) \right] \frac{RK_Y}{I_T} \left(\frac{1 + \frac{M_A}{M_O}}{-A + \alpha^2} \right) \tag{D.24}$$

The two angles θ and ψ and their rates are thus determined.

Appendix E
ESMRO FUNCTIONAL FLOW DIAGRAMS

The functional flow diagrams (FFD) for the ESMRO Mission are presented in this Appendix, (Figs. E-2 through E-33). A tree of the FFD's developed for this study program is presented in Fig. E-1. Functional analysis is a rigorous systems review that details the functional flow and operations of the program phases. The analysis procedure followed has been to define the major steps required to conduct an ESMRO mission as shown in the top level functional flow diagram, Fig. E-2. Of the eight functional operations shown, only the "Perform ESMRO Mission" function has been analyzed in more detail, since it is the main objective of the ESMRO study program. Further, the development of FFD's in this branch was only carried to the levels necessary to permit definition of program requirements.

Applicable definitions are given in the following paragraphs

Reference Blocks. Each functional area is defined on a single page. The functional area being defined is presented as the reference function on the left, and all FFD's terminate into applicable functional reference areas on the right.

Flow. The functional flow diagrams read, or flow, from left to right. Satisfactory flow consists of entering the block on the left, and exiting the block on the right.

NOT. Unsatisfactory flow, or "Not" flow is to leave the functional block out of the bottom.

"OR" Gate. OR gates are used in the FFD's to indicate a choice between alternate paths to be taken in following the functional flow.

"AND" Gate. AND gates are used in the FFD's to indicate a parallel capability of completing two or more functional operations. An "and" gate requires all just past functional operations to be completed before continuing to the next function.

CM. In the case a "not" flow is encountered, a Correct Malfunction (CM) operation is indicated which would be implemented for the applicable functional operation.

Applicable abbreviations are as follows:

- AAP - Apollo Applications Program
- ESMRO - Experiments for Satellite and Material Recovery from Orbit
- FFD - Functional flow diagram
- EVA - Extra vehicular activity
- ΔV - Delta velocity

- T/S - Target satellite
- S/C - Spacecraft
- CM - Correct malfunction
- NASA - National Aeronautics and Space Administration

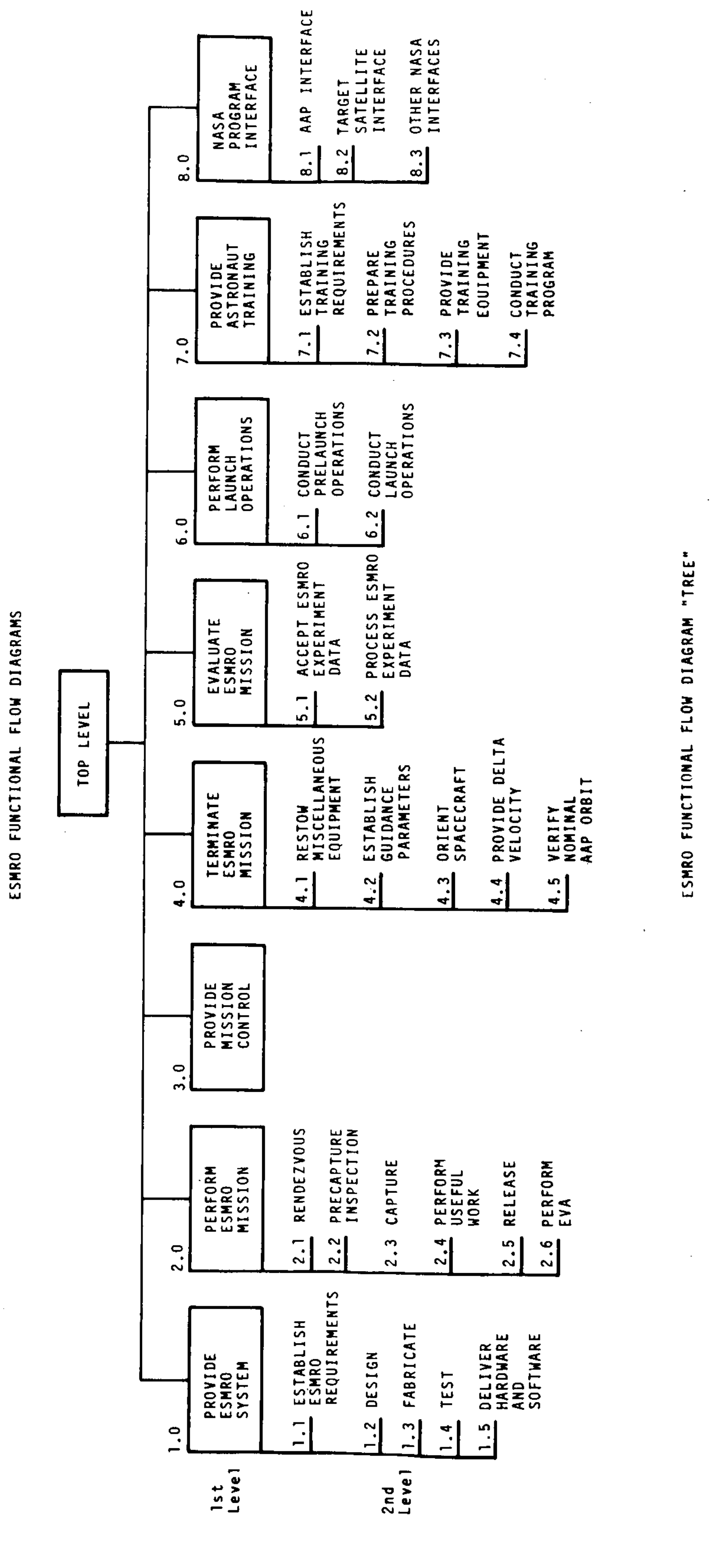

Fig. E-1 ESMRO Functional Flow Diagram Tree

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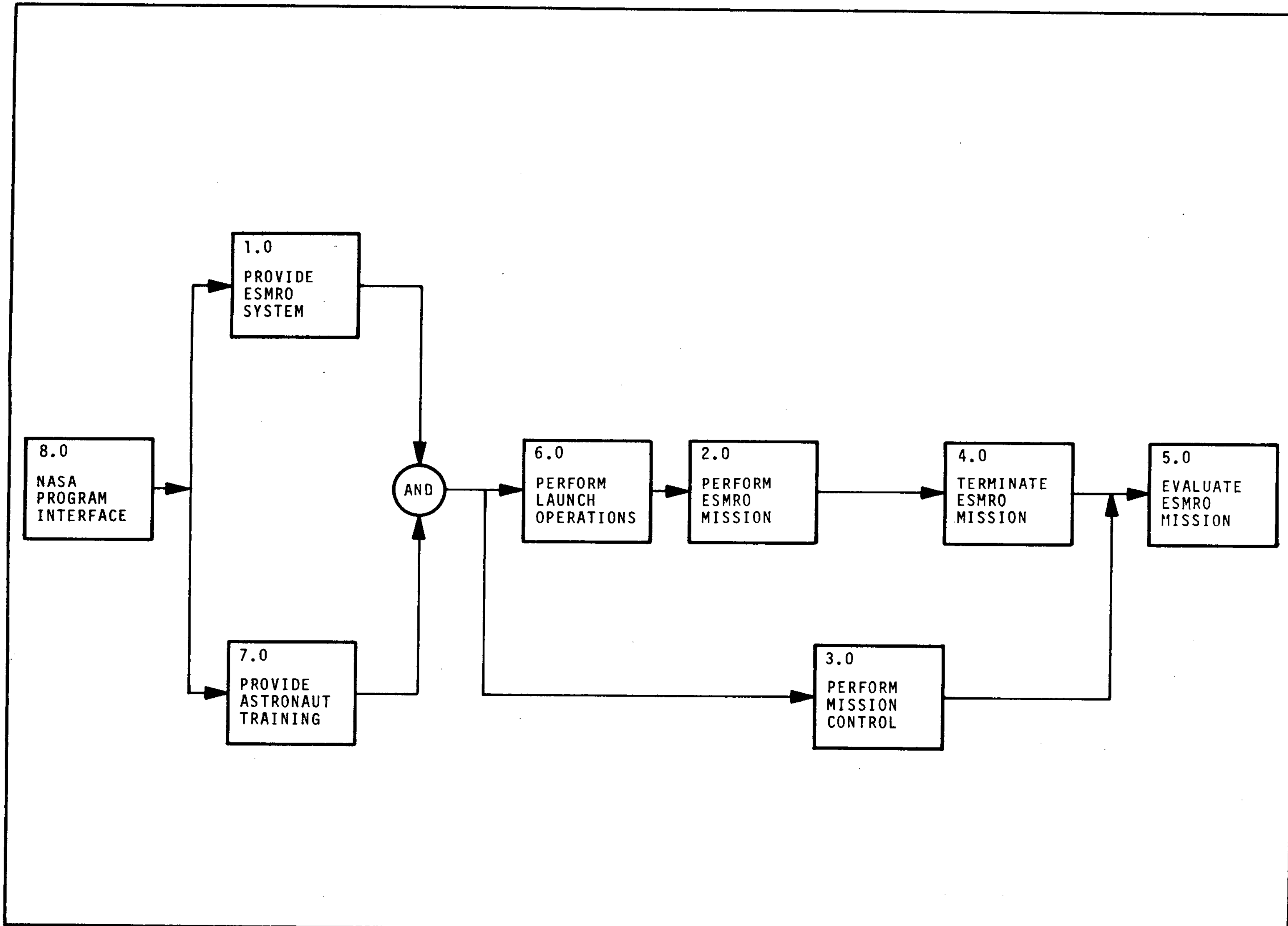

Fig. E-2 ESMRO Functional Flow Diagram - Top Level

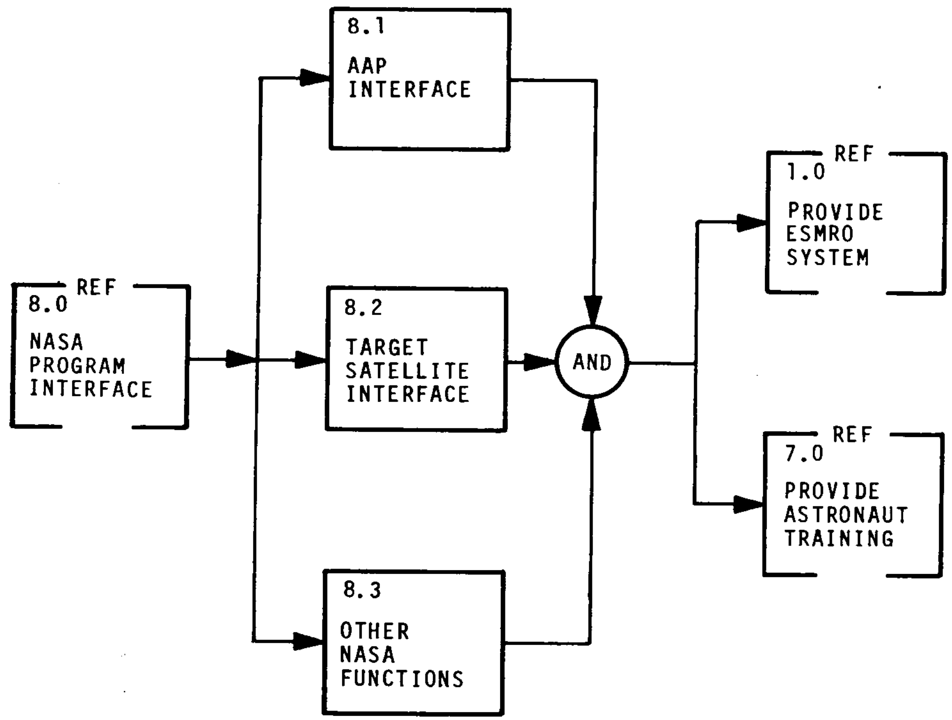

Fig. E-3 NASA Program Interface - FFD

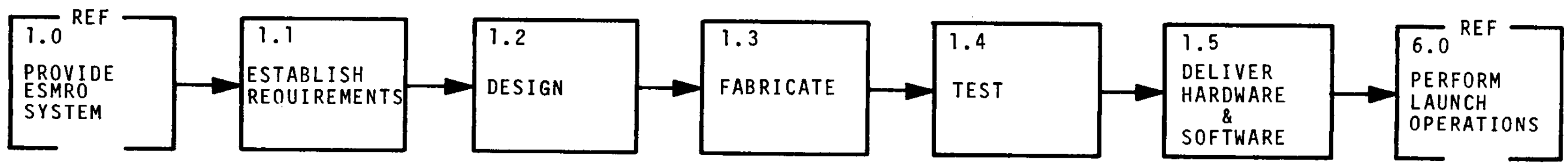

FIG. E-4 PROVIDE ESMRO SYSTEM - FFD

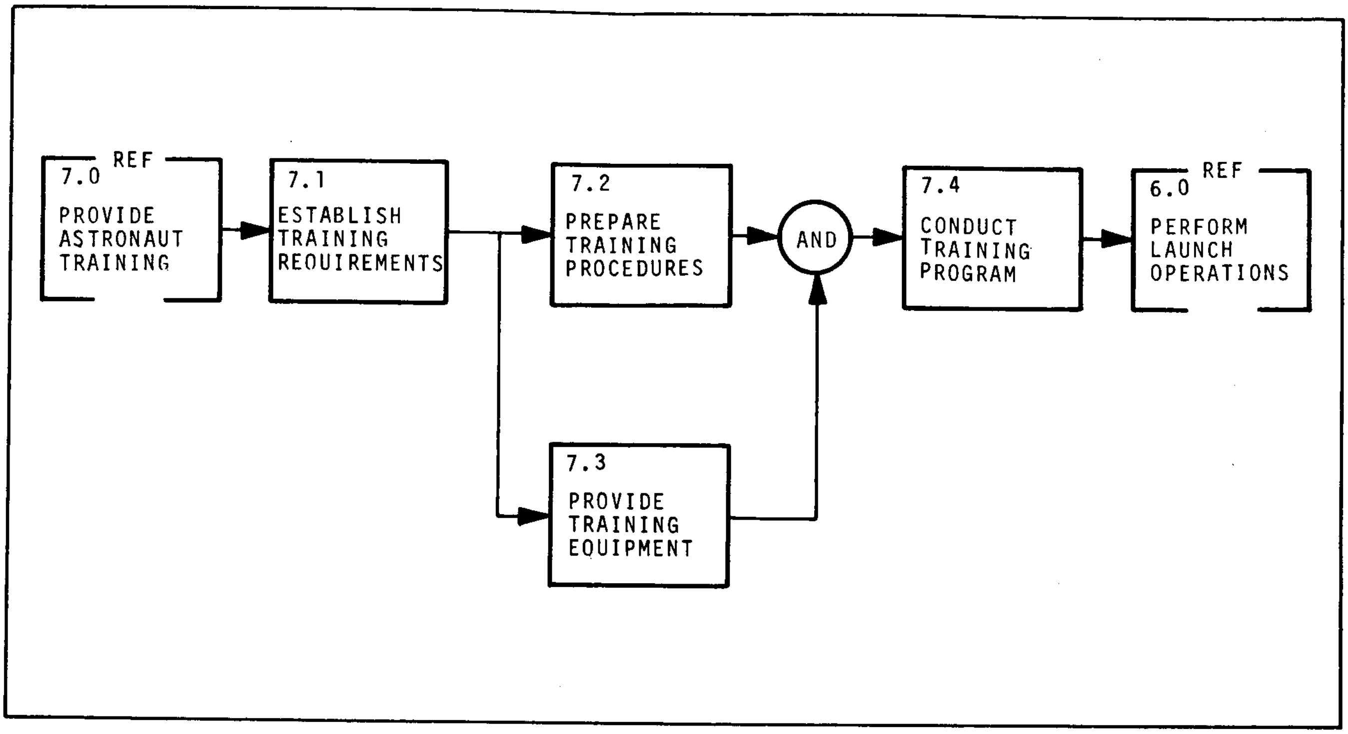

FIG. E-5 PROVIDE ASTRONAUT TRAINING - FFD

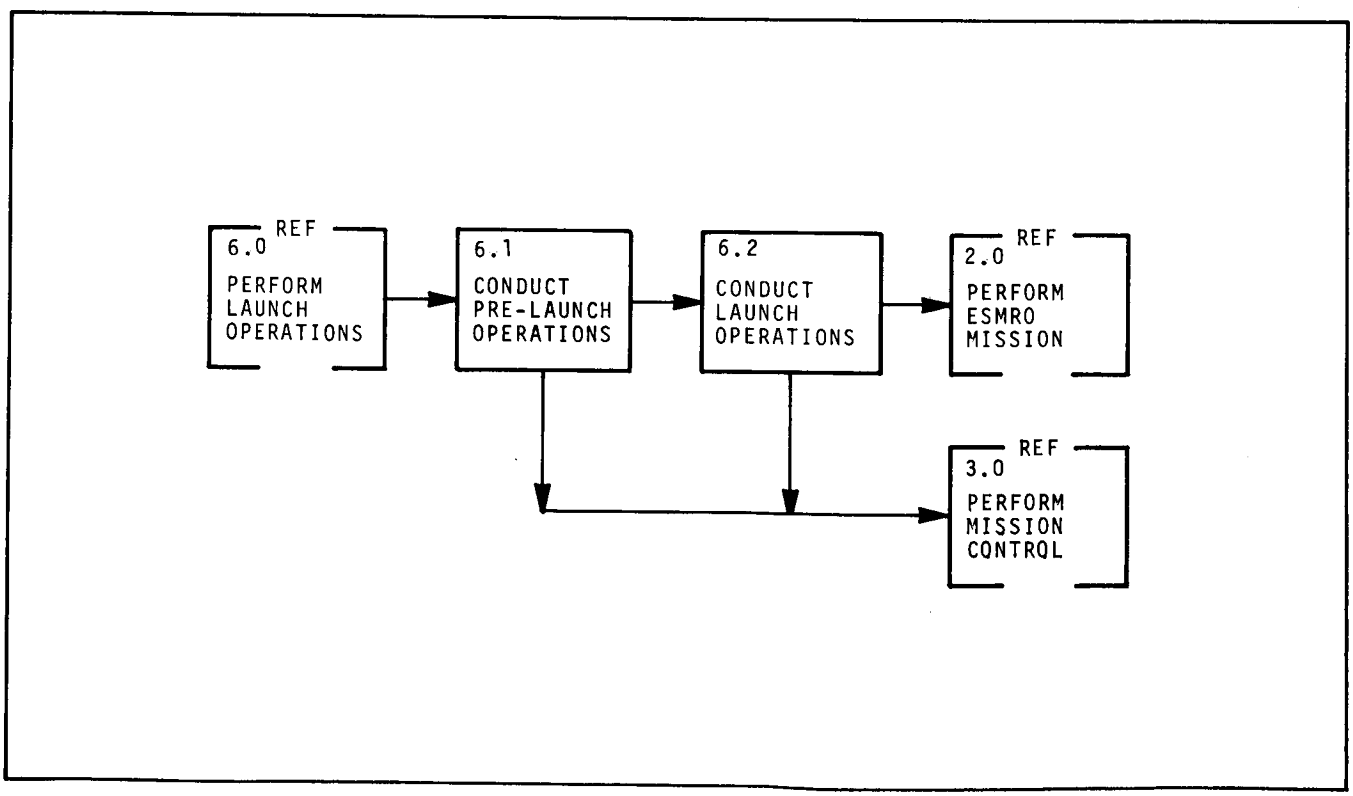

FIG. E-6 PERFORM LAUNCH OPERATIONS - FFD

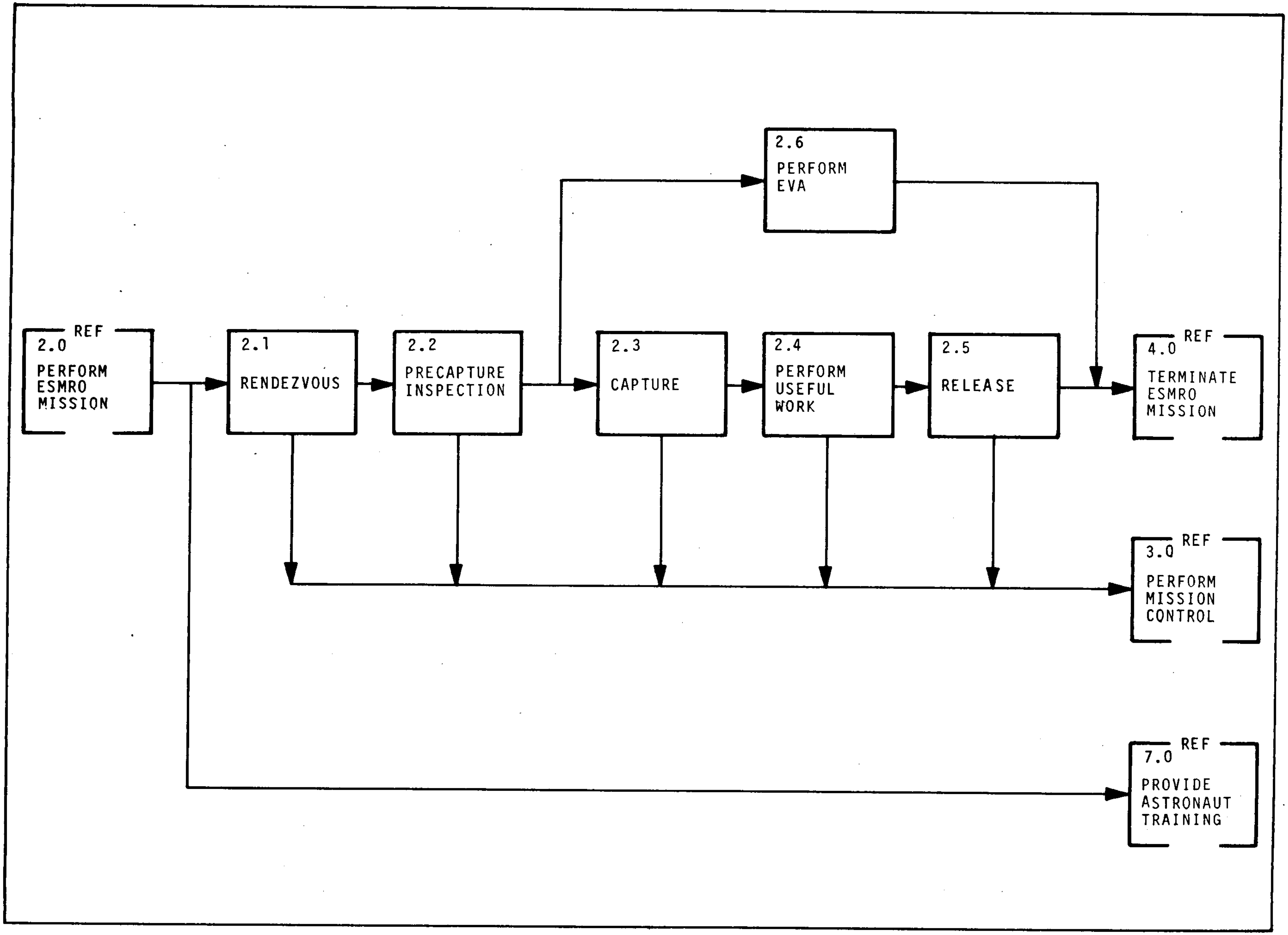

FIG. E-7 PERFORM ESMRO MISSION - FFD

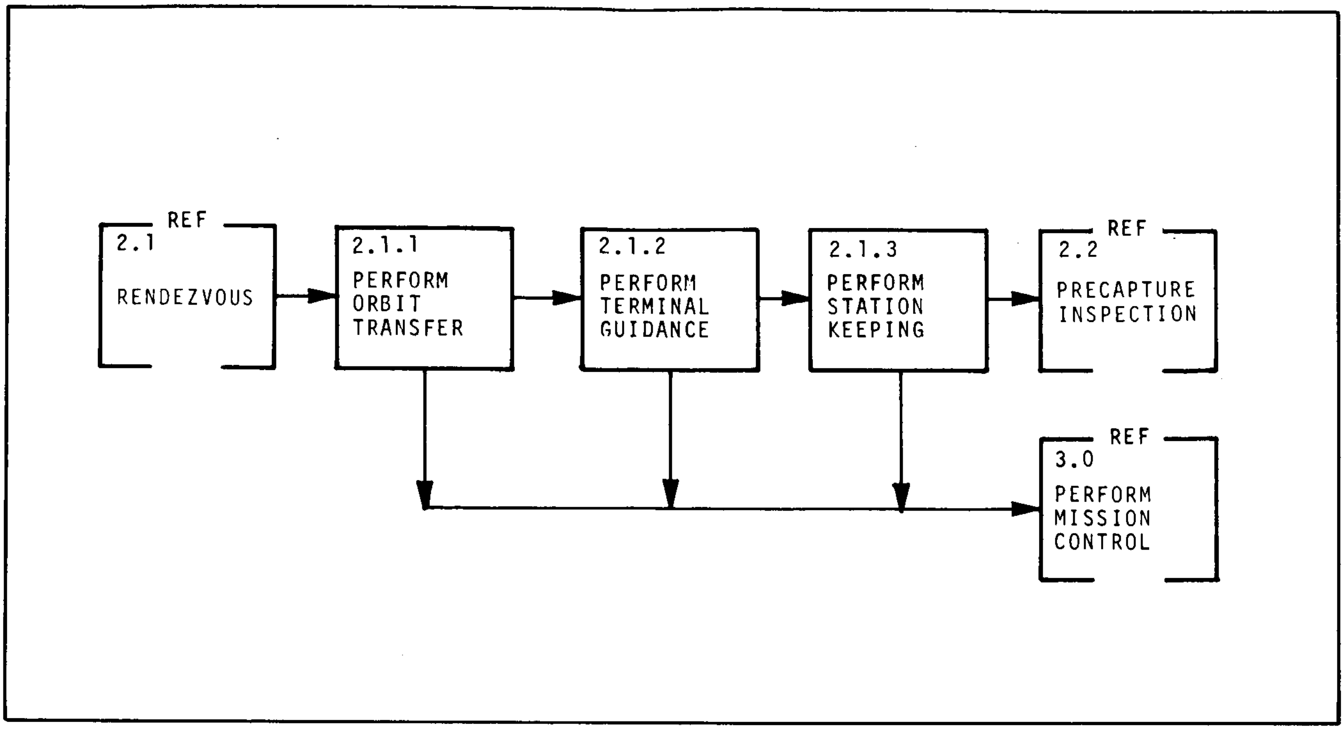

FIG. E-8 RENDEZVOUS - FFD

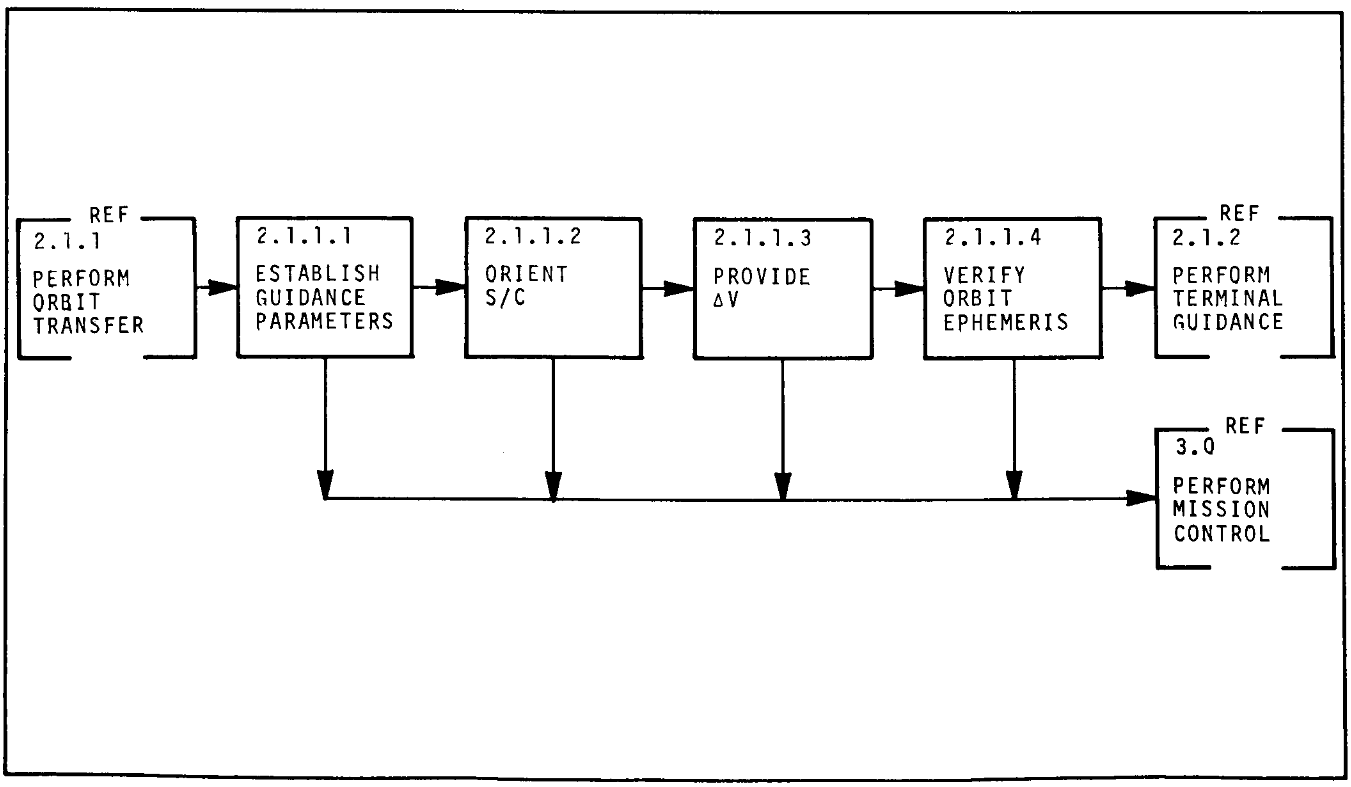

FIG. E-9 PERFORM ORBIT TRANSFER - FFD

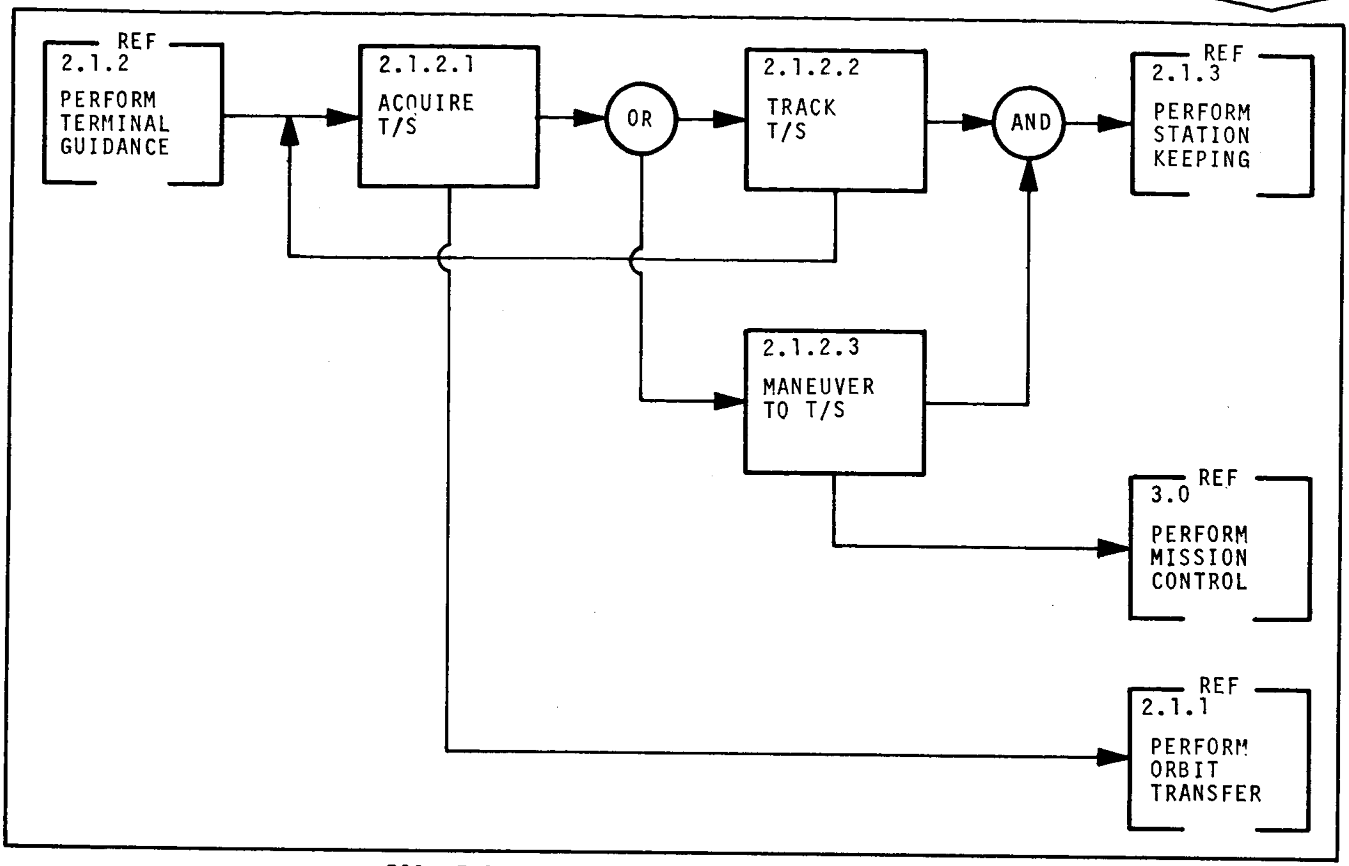

FIG. E-10 PERFORM TERMINAL GUIDANCE - FFD

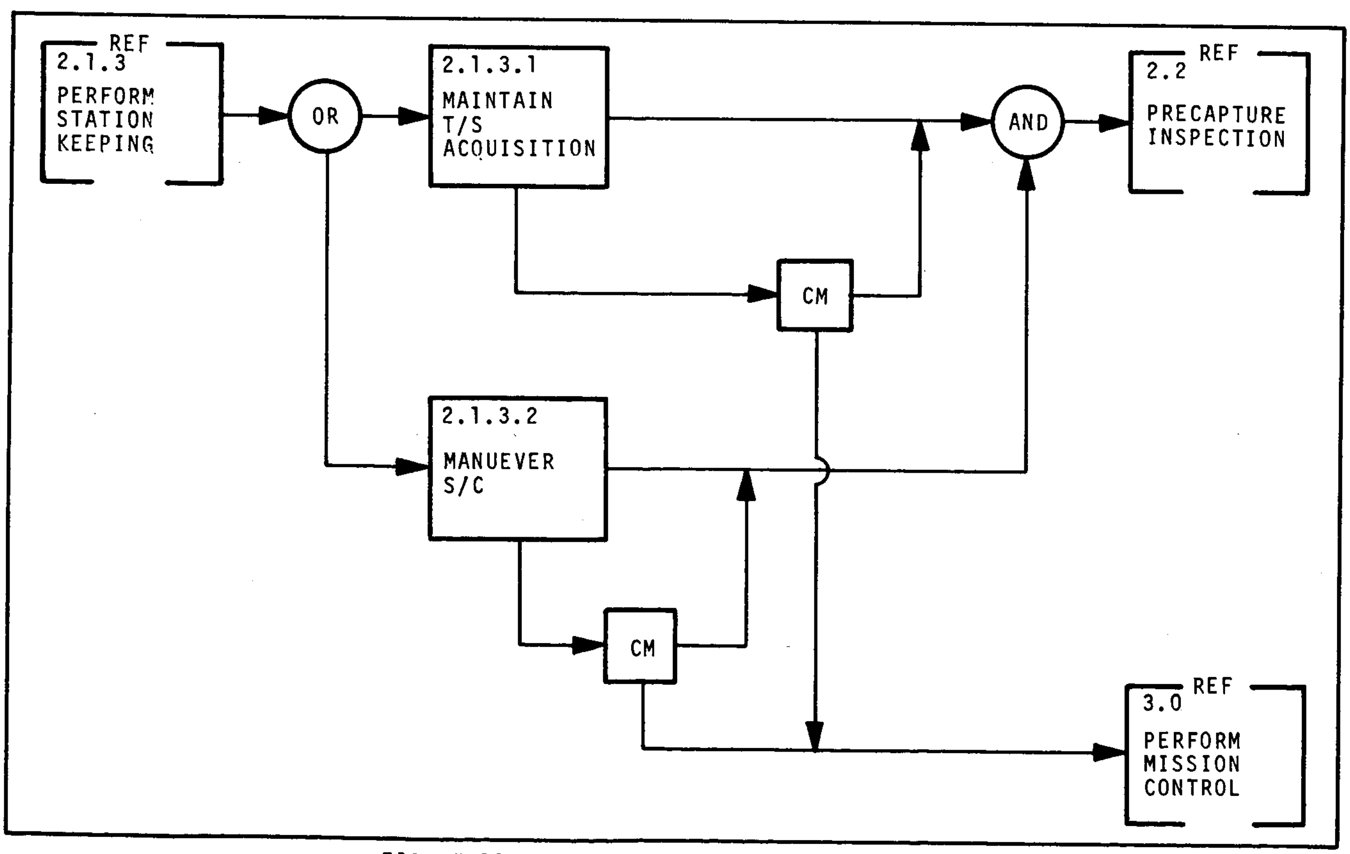

FIG. E-11 PERFORM STATION KEEPING - FFD

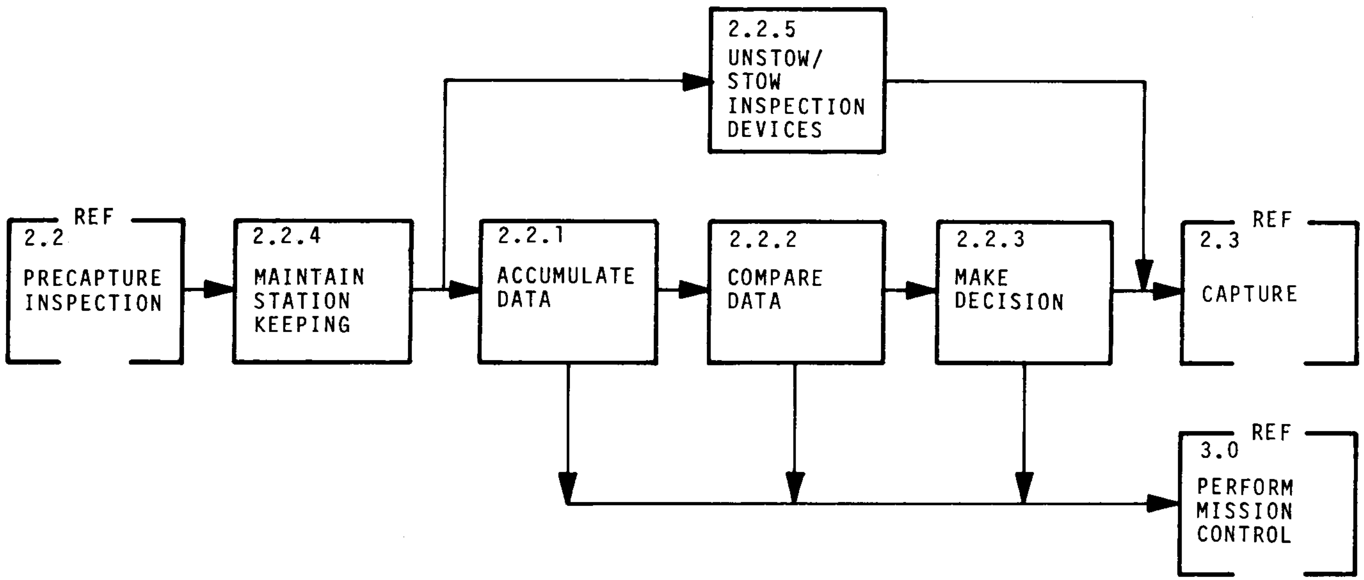

FIG. E-12 PRECAPTURE INSPECTION - FFD

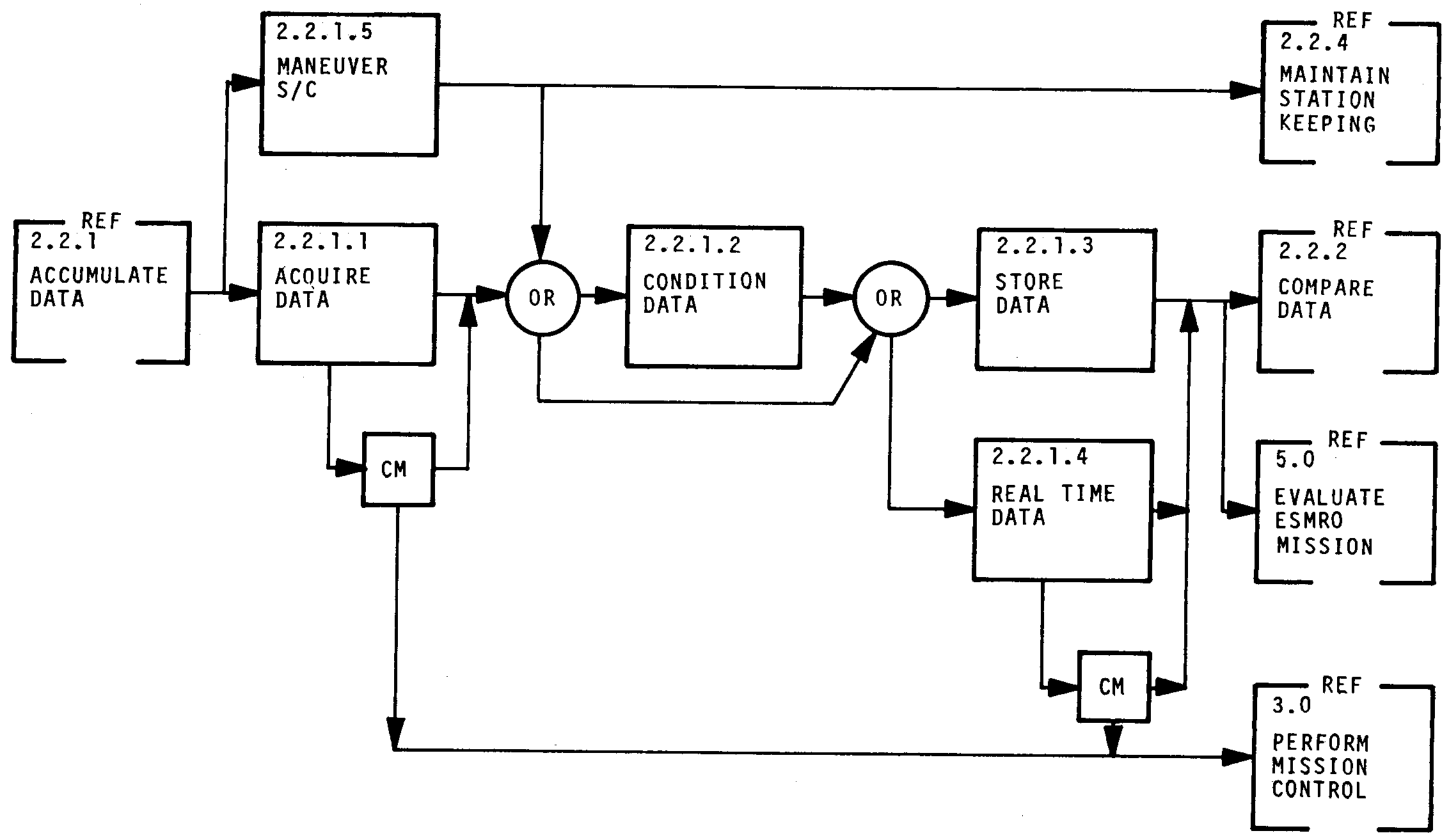

FIG. E-13 ACCUMULATE DATA - FFD

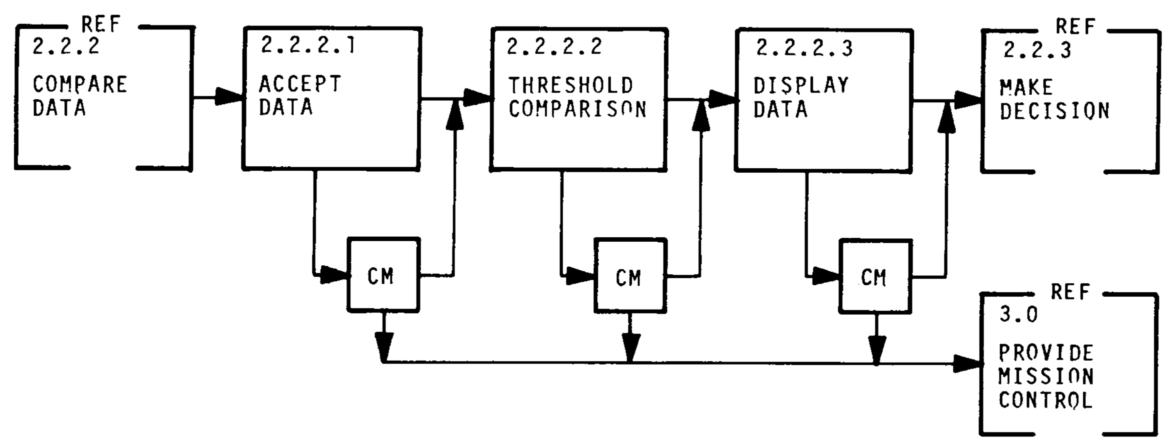

FIG. E-14 COMPARE DATA - FFD

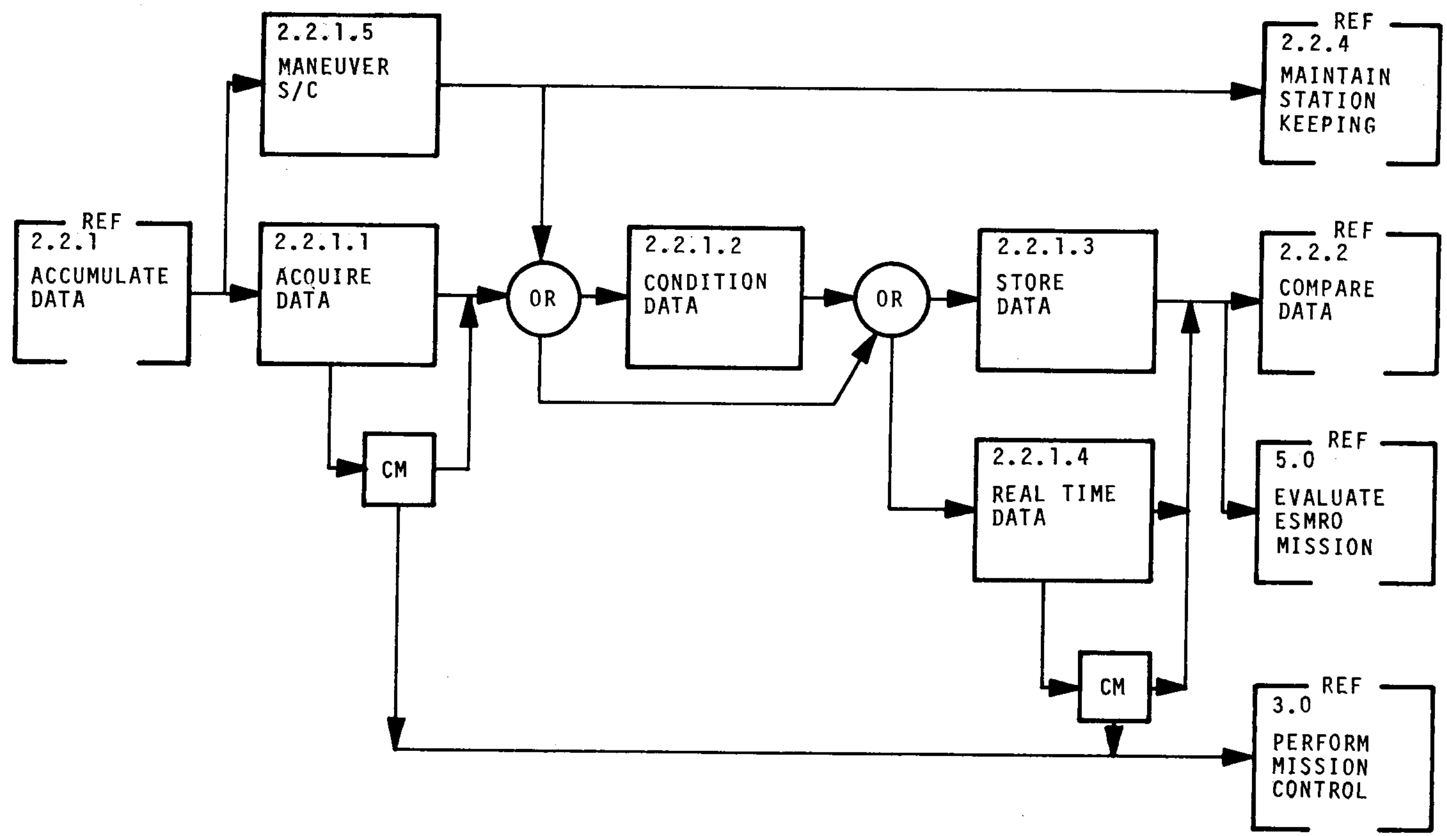

FIG. E-13 ACCUMULATE DATA - FFD

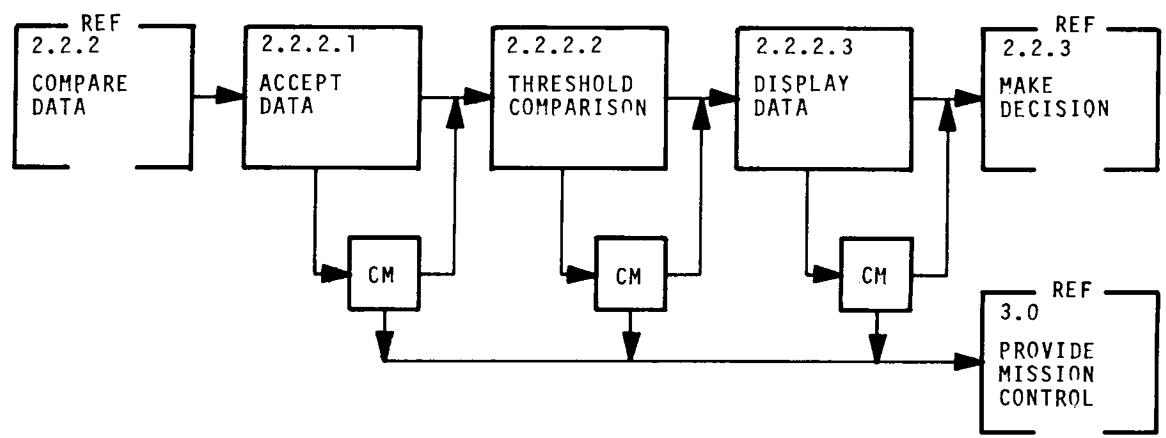

FIG. E-14 COMPARE DATA - FFD

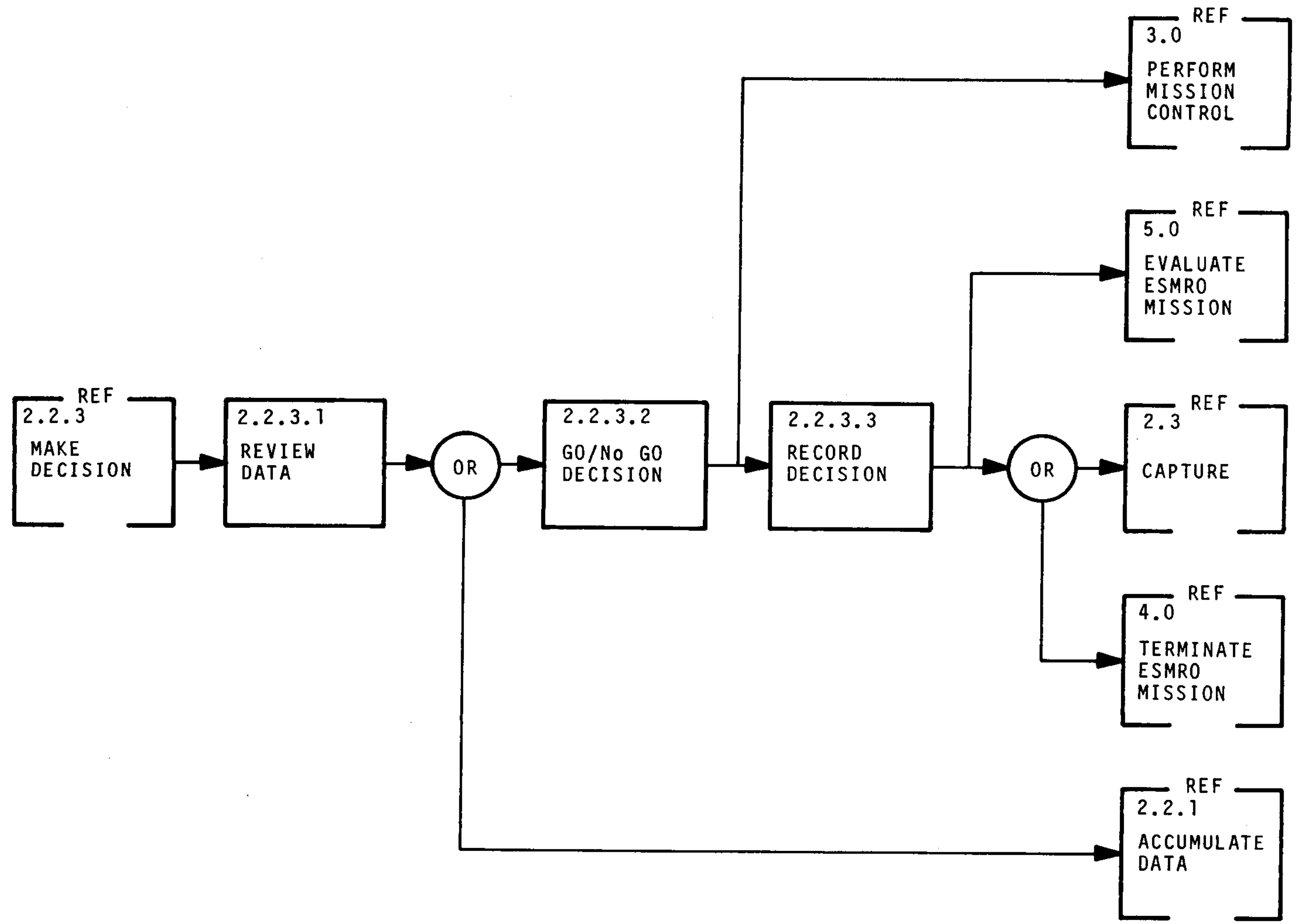

FIG. E-15 MAKE DECISION - FFD

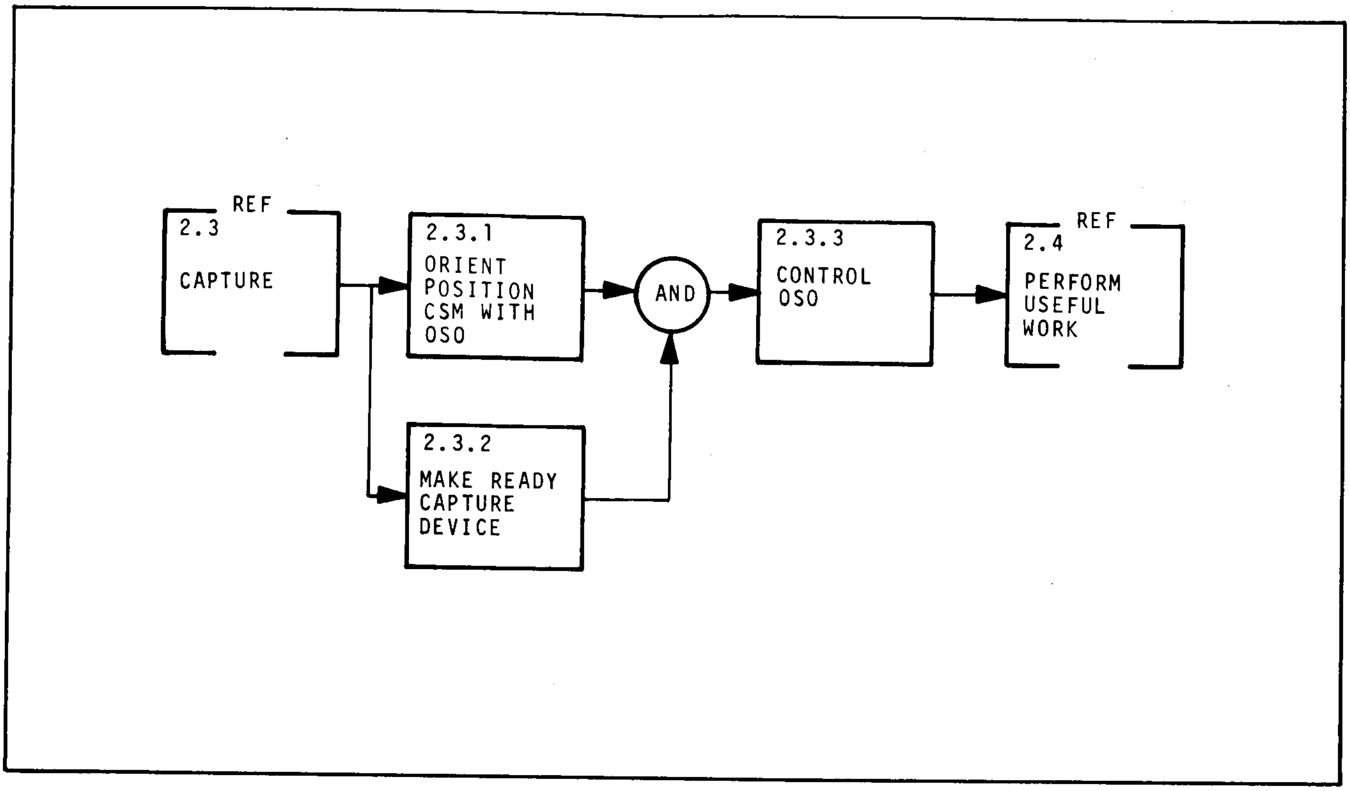

FIG. E-16 CAPTURE - FFD

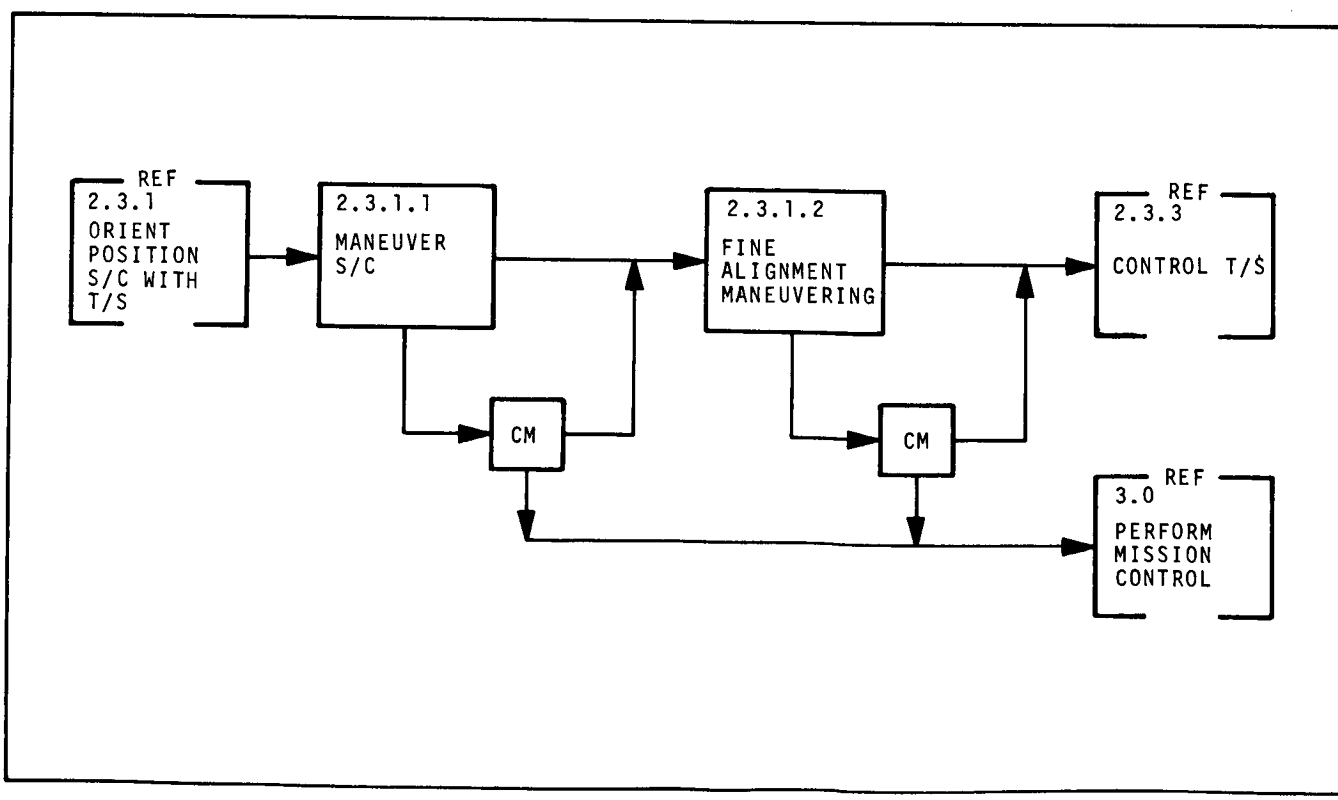

FIG. E-17 ORIENT POSITION S/C WITH T/S - FFD

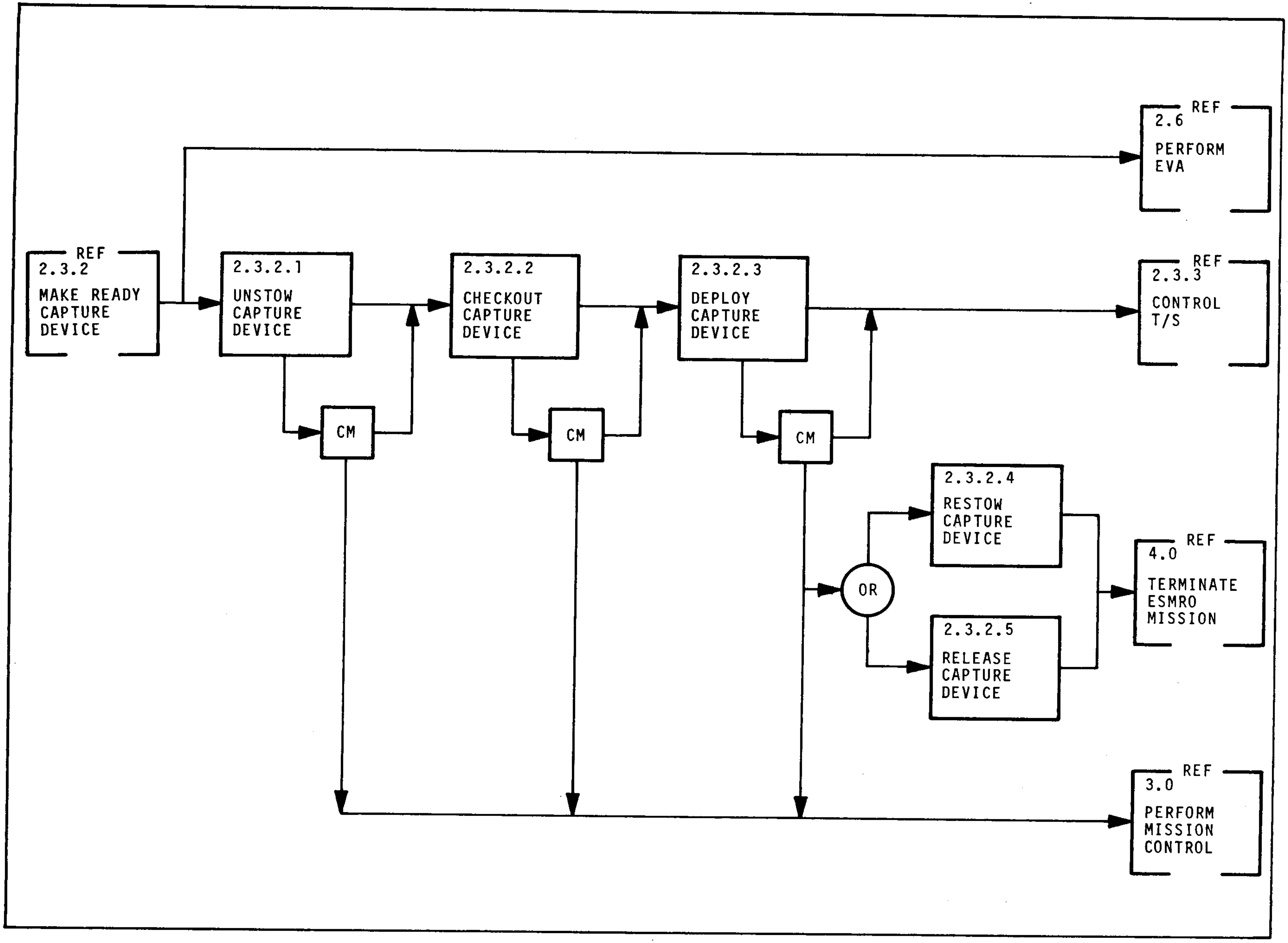

FIG. E-18 MAKE READY CAPTURE DEVICE - FFD

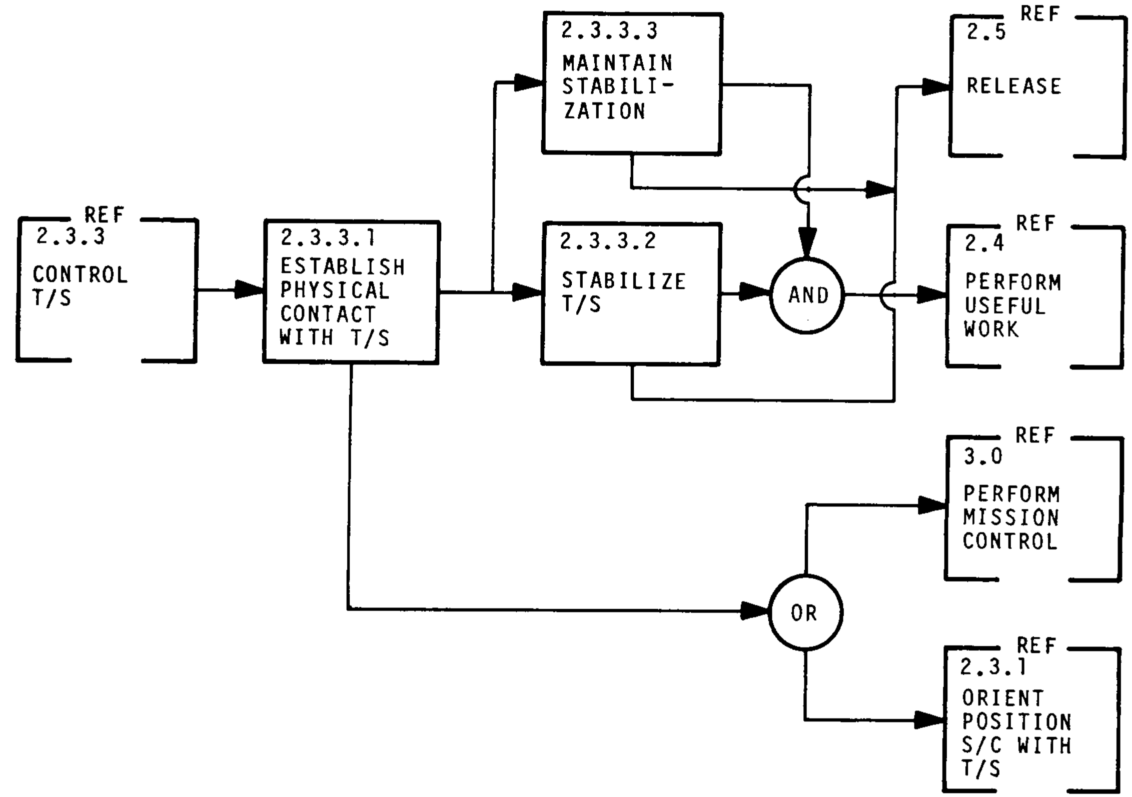

FIG. E-19 CONTROL T/S - FFD

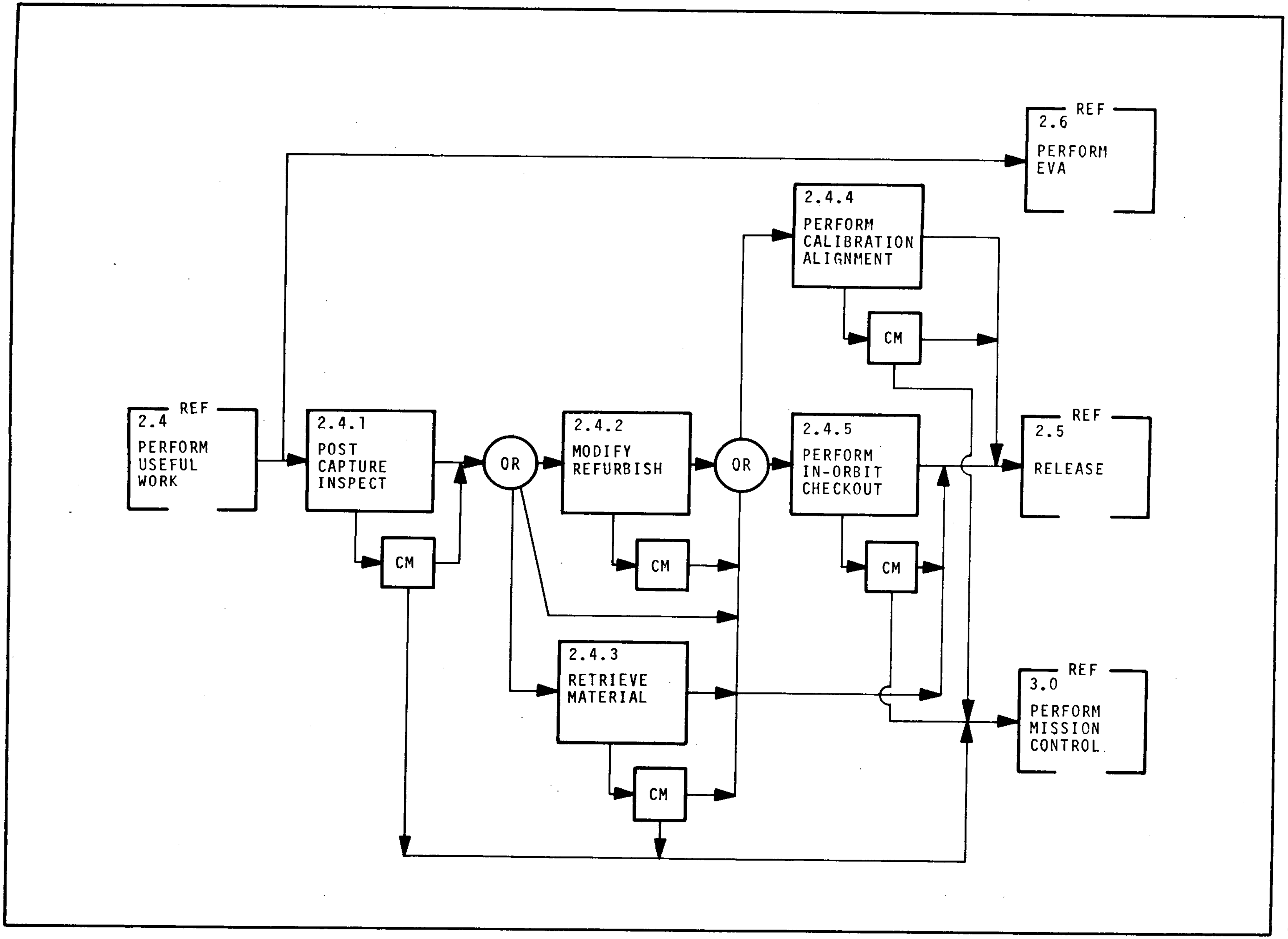

FIG. E-20 PERFORM USEFUL WORK - FFD

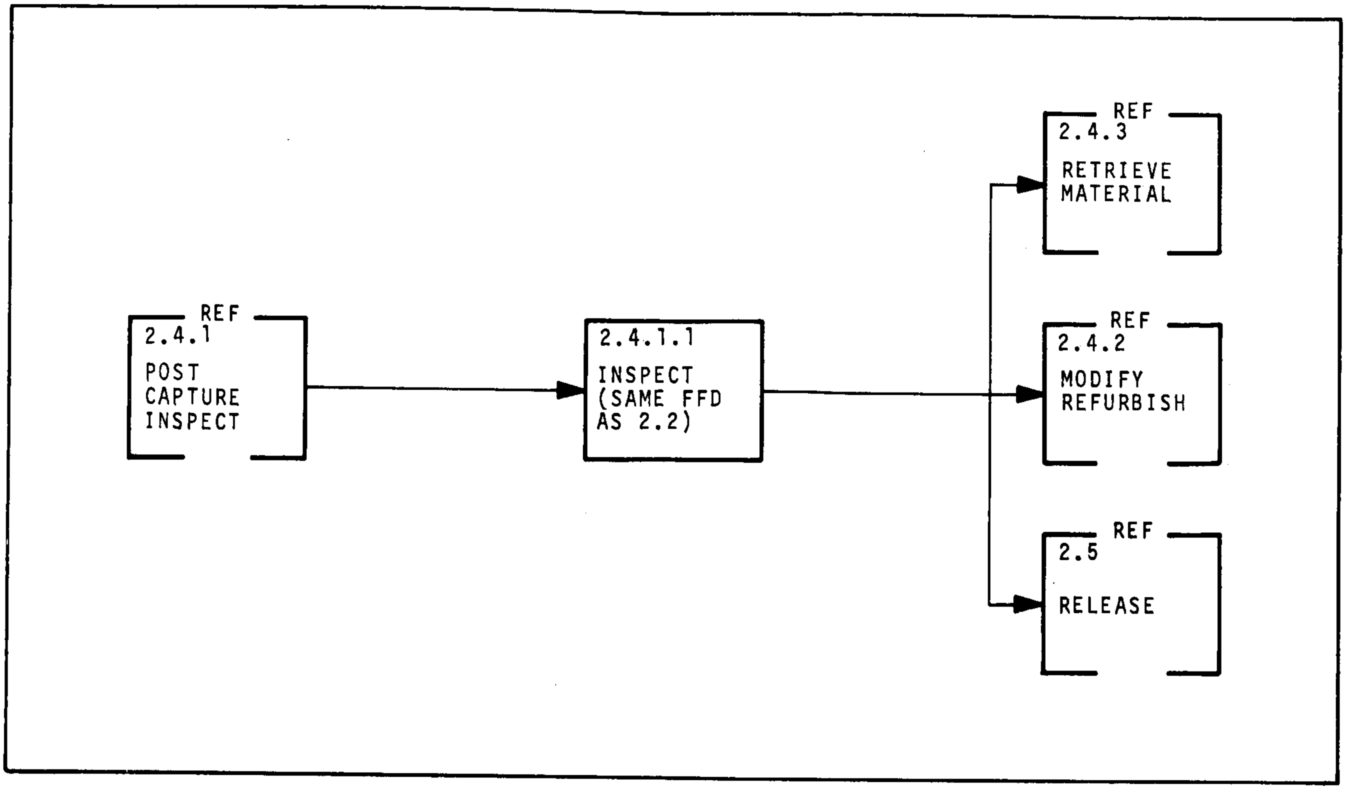

FIG. E-21 POST-CAPTURE INSPECTION - FFD

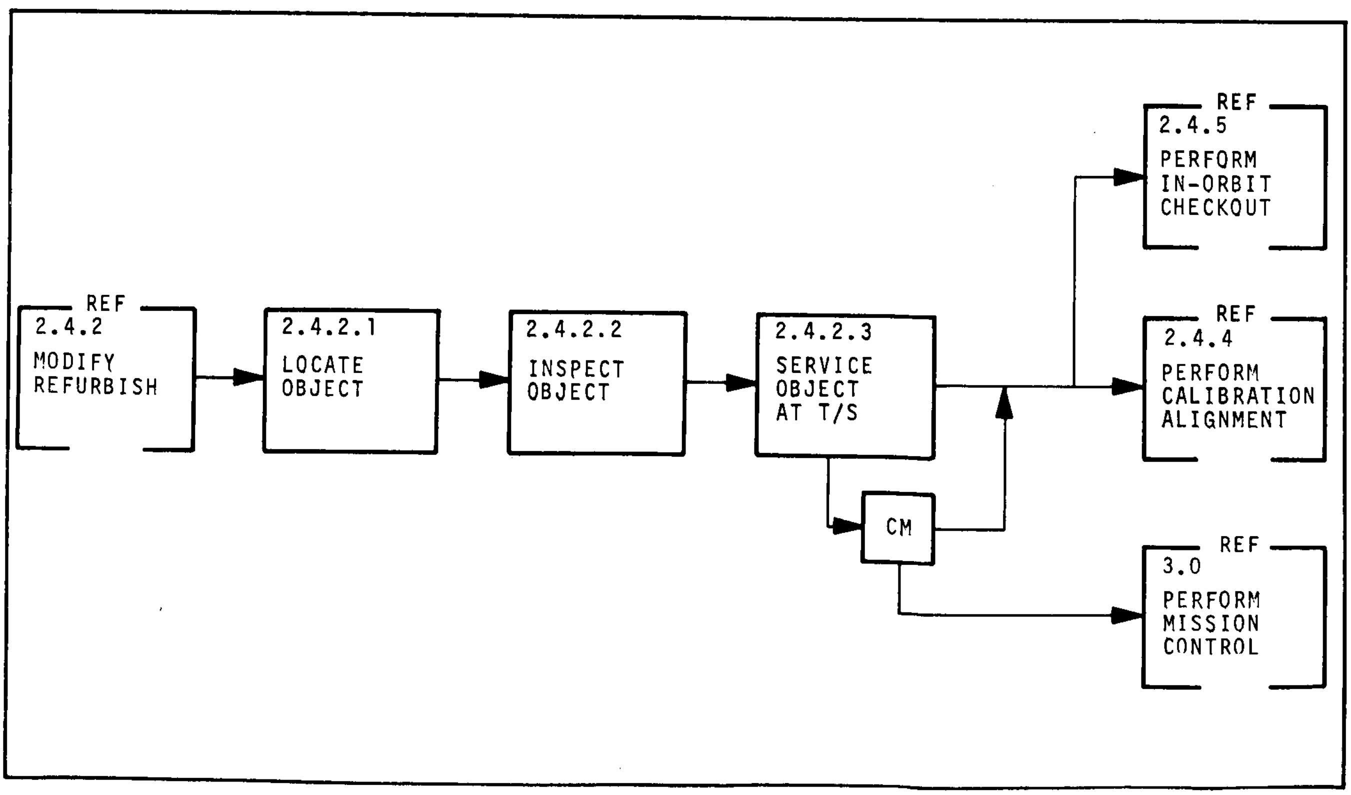

FIG. E-22 MODIFY REFURBISH - FFD

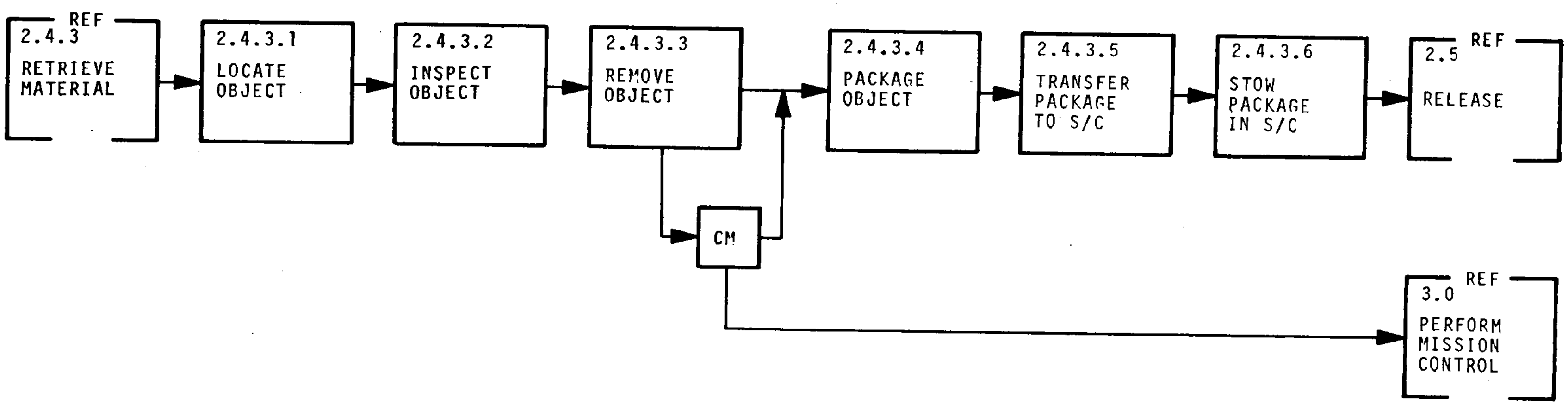

FIG. E-23 RETRIEVE MATERIAL - FFD

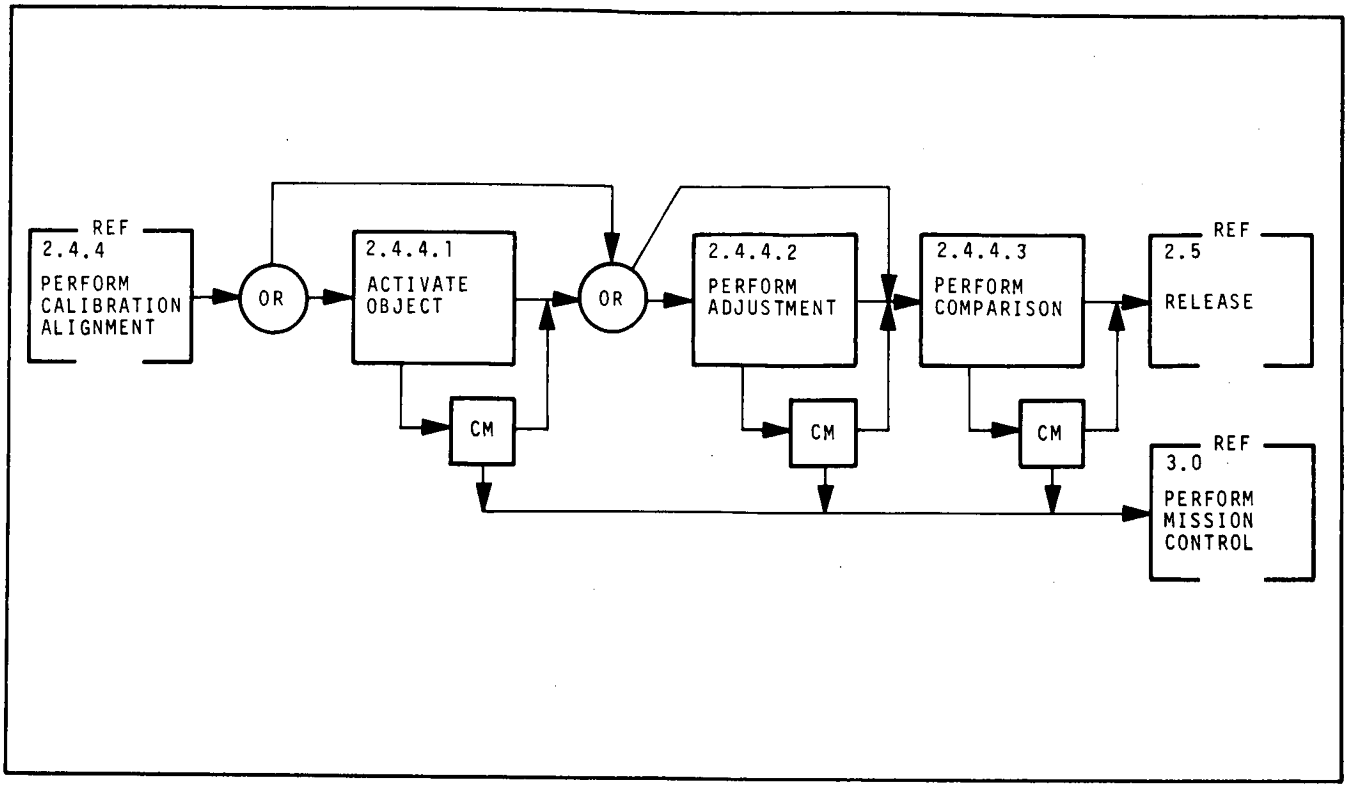

FIG. E-24 PERFORM CALIBRATION ALIGNMENT - FFD

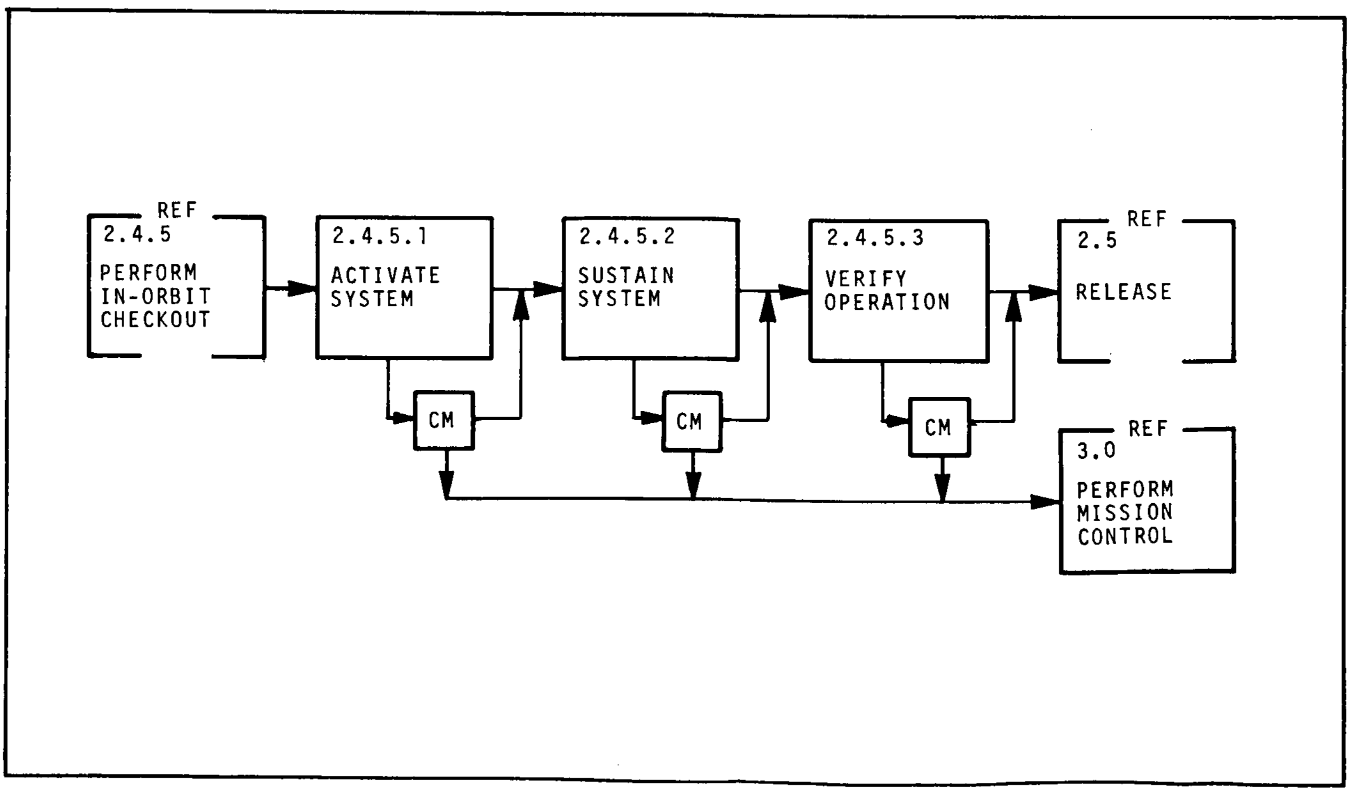

FIG. E-25 PERFORM IN-ORBIT CHECKOUT - FFD

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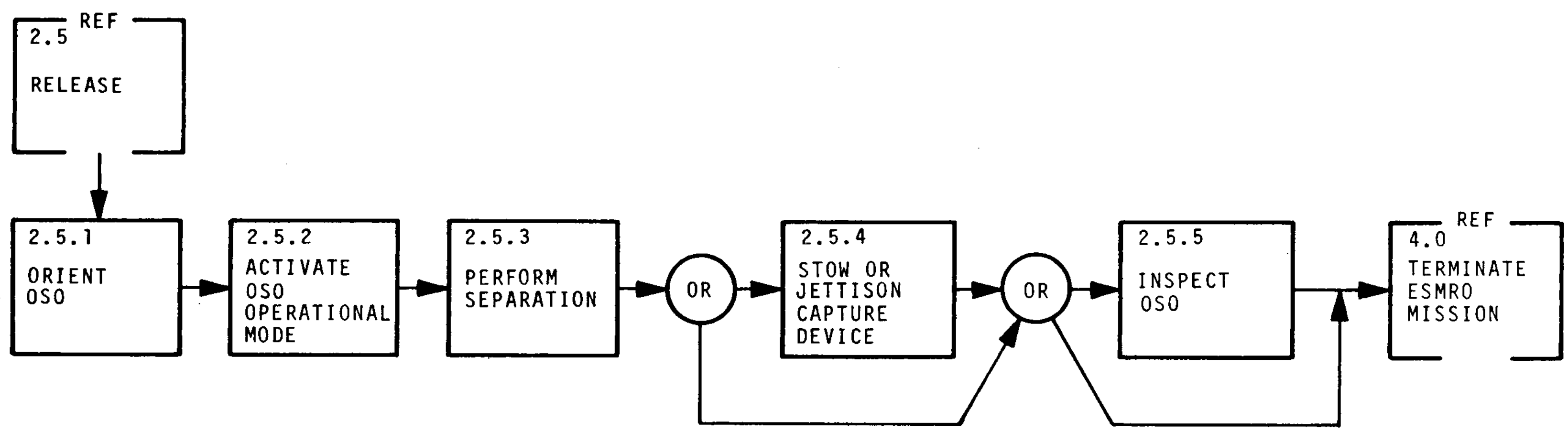

FIG. E-26 RELEASE - FFD

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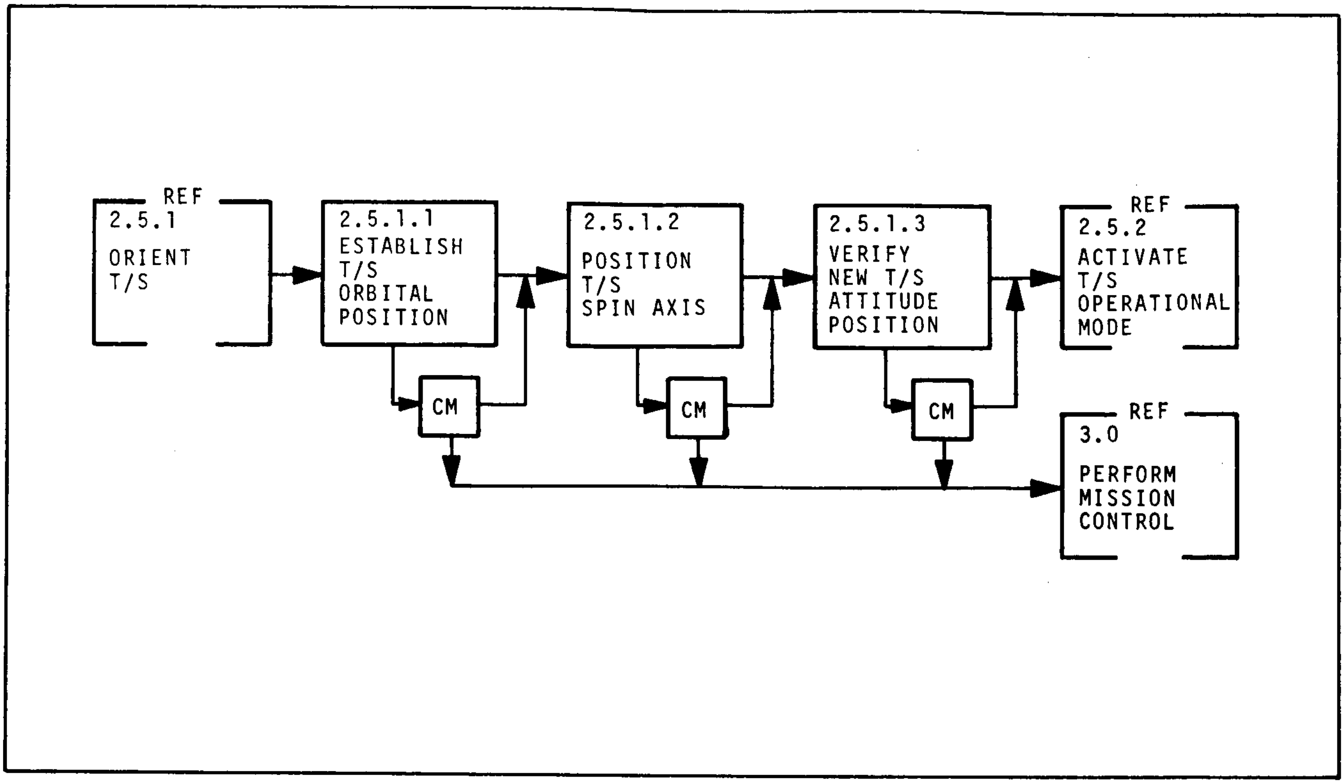

FIG. E-27 ORIENT T/S - FFD

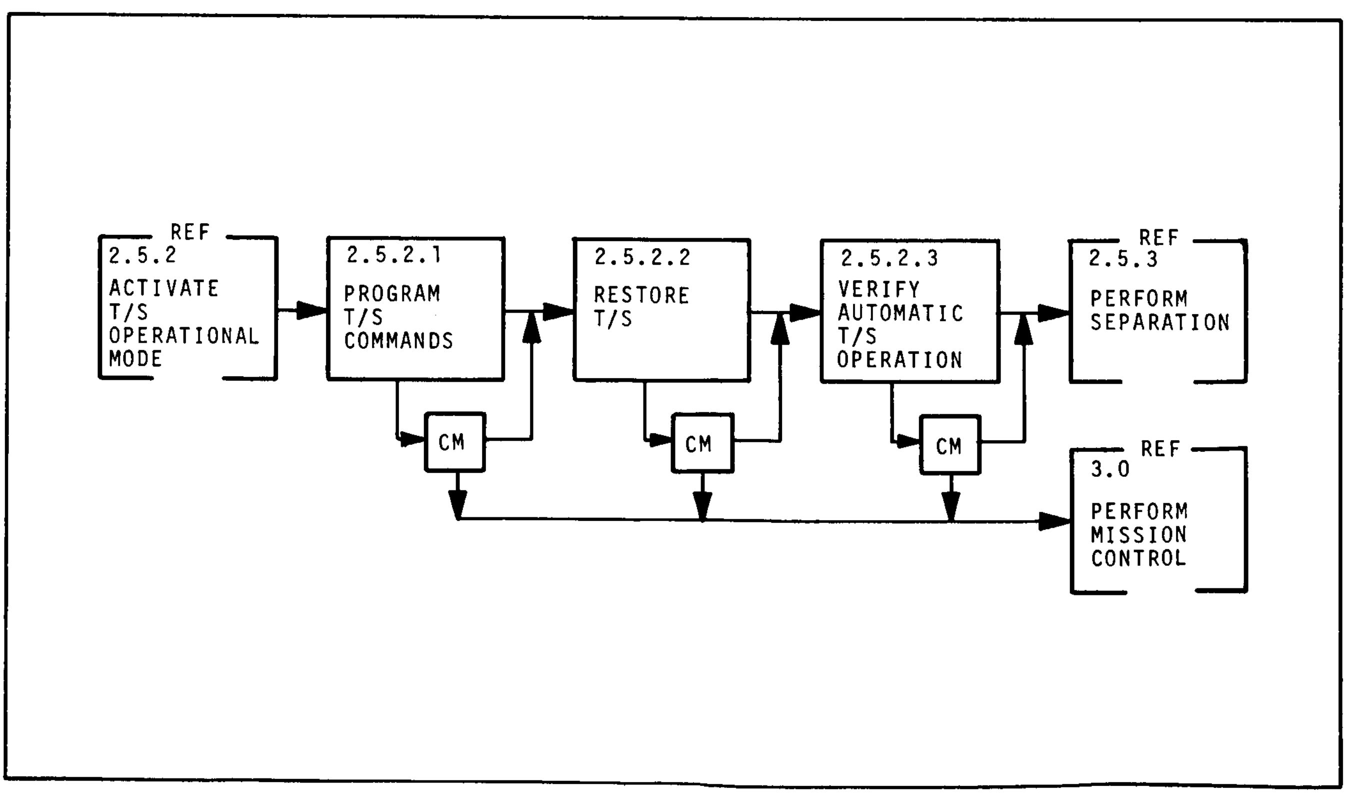

FIG. E-28 ACTIVATE T/S OPERATIONAL MODE - FFD

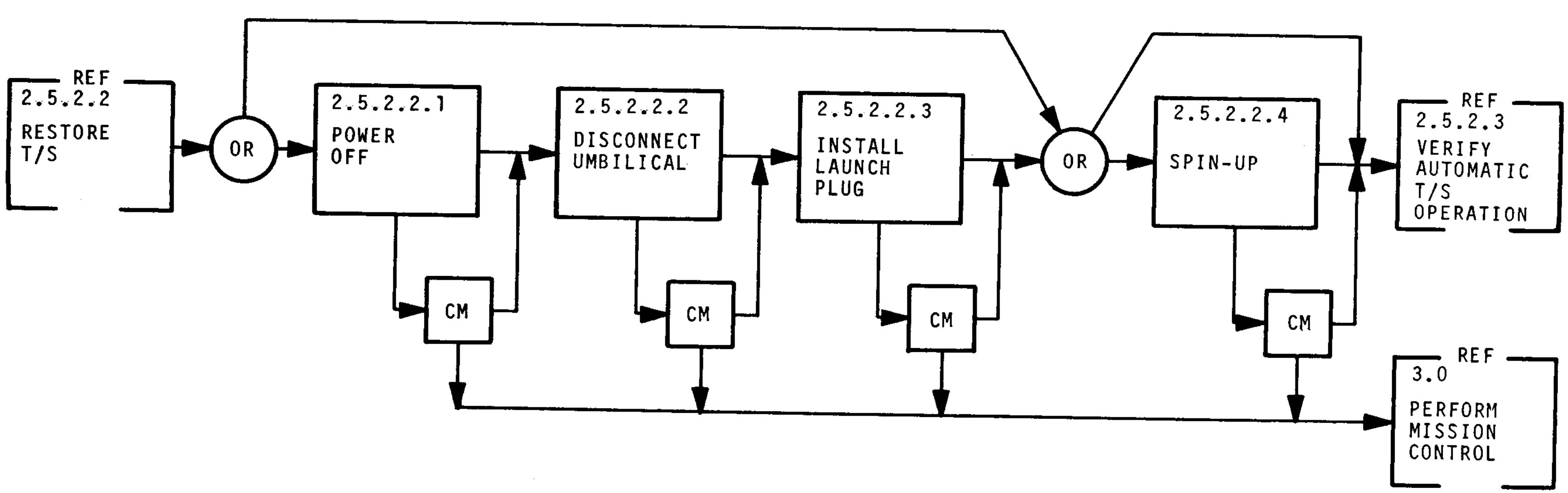

FIG. E-29 RESTORE T/S - FFD

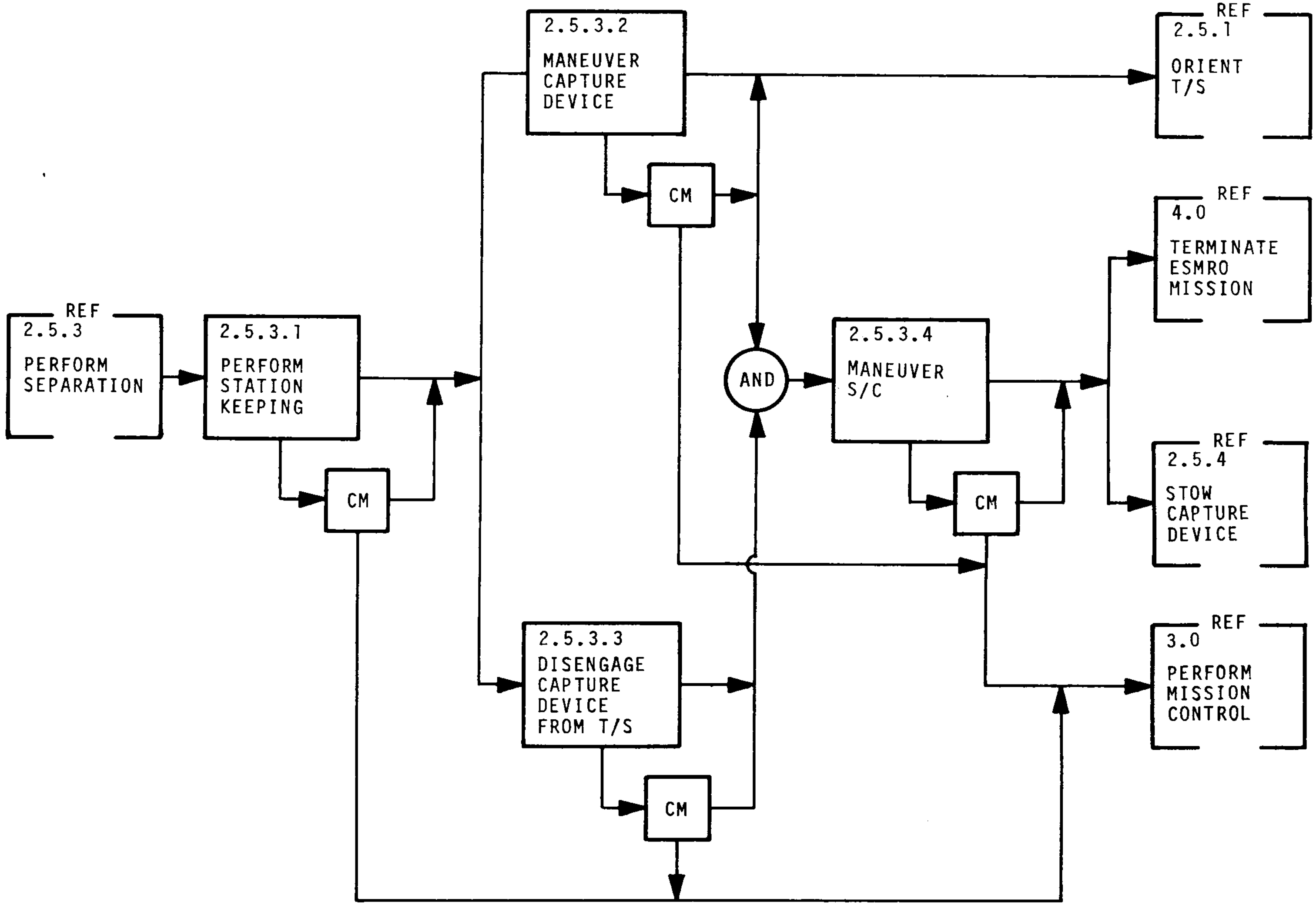

FIG. E-30 PERFORM SEPARATION - FFD

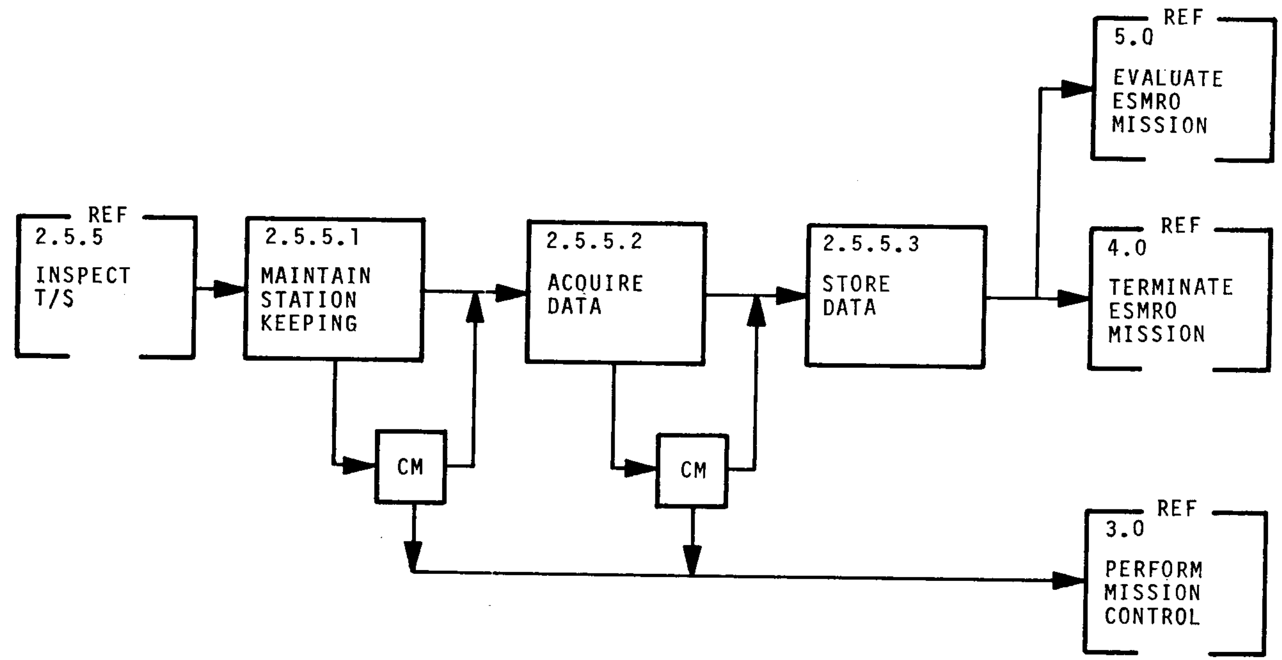

FIG. E-31 INSPECT T/S - FFD

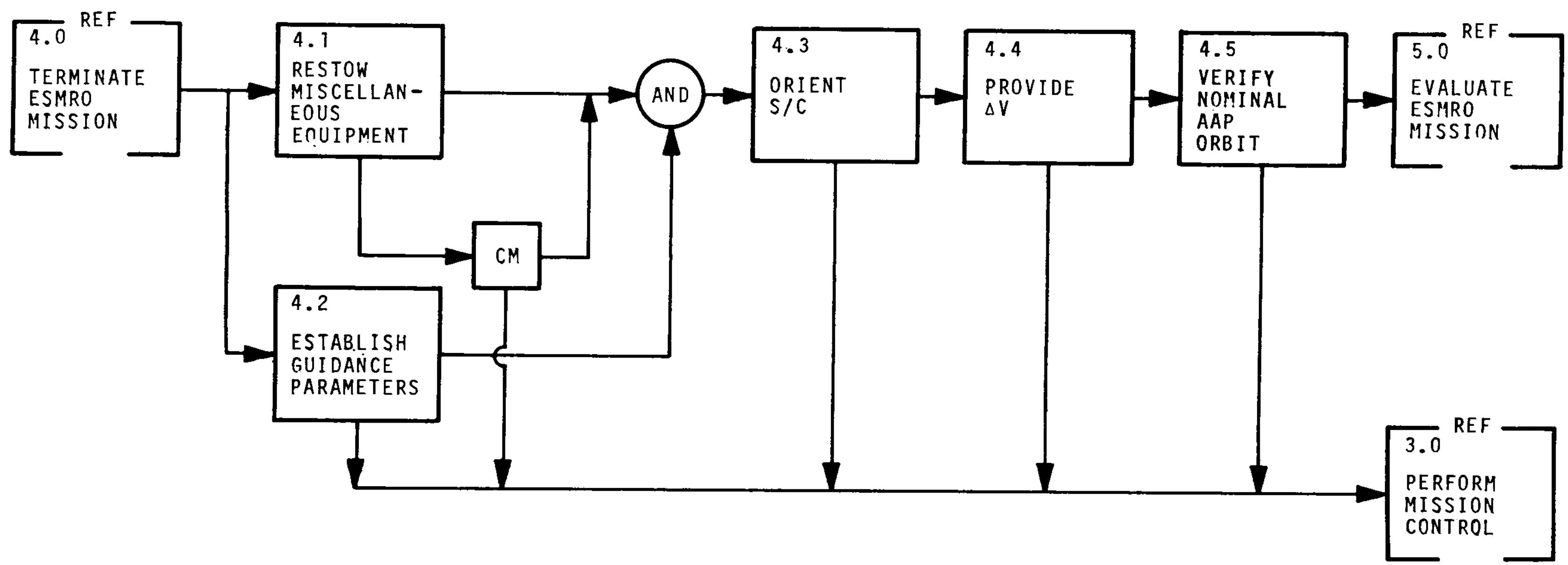

FIG. E-32 TERMINATE ESMRO MISSION - FFD

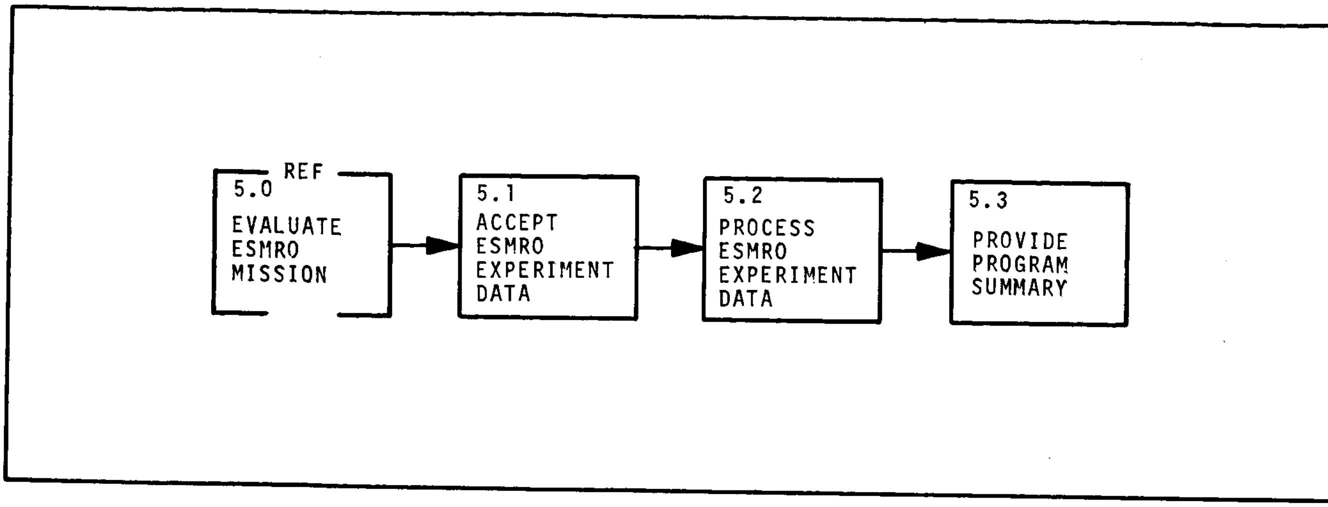

FIG. E-33 EVALUATE ESMRO MISSION - FFD